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MOBILITY ANALYSES OF STANDARD- AND HIGH-MOBILITY TACTICAL SUPPORT VEHICLES (HIMO STUDY)

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Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

February 1976

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The mobility performances of standard- and high-mobility support vehicles were compared on the basis of performances predicted with the Army Mobility Model (AMM) in several terrain and weather conditions.

Preparation of terrain maps for a 30- by 100-km area in the Mid-East and another in West Germany, scenarios used to supply combat units, and vehicle performance predictions for each of 17 vehicles doing tasks determined by means of scenario map play are described. The vehicles are: M561, M656, M520E1, M559, M553, M548E1, M151A2, M715E1, M35A2, M49A2C, M813, M821, M816, M121F1, M818-

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M127A1C, TDW901, and M60A2. Vehicles are compared by means of (a) on- and off-road speed profiles, (b) mobility indices, (c) average speed over entire supply network, (d) average speed for tactical jobs, (e) average speed as a percentage of off-road travel, and (f) travel time to complete average job. A quantification of 1972 DA WHEELS study definitions of levels of mobility is proposed, and the final vehicle evaluations are based largely on these quantified definitions.

Appendix A gives a brief description of AMM. Appendix B describes the mobility map preparation. Appendix C describes preparation of travel network data. Appendix D details various statistical examinations of vehicle performance in the two study terrains. Appendix E describes procedures to compute rating speeds in accordance with the quantified WHEELS study definitions. Appendix F lists the data used to characterize the vehicles. Appendix G lists the participants in scenario exercises.

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PREFACE

This study was conducted during the period May 1974 to June 1975 by personnel of the U. S. Army Engineer Waterways Experiment Station (WES) for the U. S. Army Training and Doctrine Command (TRADOC) under Intra-Army Orders for Reimbursable Services No. CD-22-74 dated 3 May 1974 and CD-16-75 dated 8 October 1974 with Change 1 dated 10 June 1975. The study was also supported by the U. S. Army Tank-Automotive Command (TACOM), whose Engineering Sciences Division aided in the preparation of necessary terrain data describing linear features and exercised the AMC Mobility Model (AMM) to make all predictions of vehicle performance in negotiating linear features.

The study was conducted under the general supervision of Messrs. W. G. Shockley, Chief, Mobility and Enviornmental Systems Laboratory (MESL), A. A. Rula, Chief, Mobility Systems Division (MSD), MESL, and C. J. Nuttall, Jr., Chief, Mobility Research and Methodology Branch (MRMB), MSD. Supporting activities at the U. S. Army Tank-Automotive Command were accomplished under the direction of Dr. J. G. Parks, Chief, Engineering Sciences Division, and Mr. Z. J. Janosi, Chief, Methodology Function Directorate. Messrs. Nuttall and D. D. Randolph, MRMB, directed the overall development and analyses. Messrs. J. H. Robinson, W. E. Willoughby, and D. Andrews, Mobility Investigations Branch (MIB), MSD, directed the preparation of terrain factor and other terrain descriptive maps. Mr. R. G. Temple, MRMB, prepared supply route network maps from job overlay maps. Mr. R. P. Smith, Data Handling Branch, (DHB), MSD, supervised digitizing of all maps and with Mr. B. Wright, DHB, prepared the vehicle performance predictions and some computer programs used in the study. Mr. R. B. Ahlvin, DHB, prepared the major new computer programs needed for the study. Mr. N. R. Murphy, MRMB, prepared the ride dynamics and obstacle height speed relations used in this study. Mr. C. E. Green, MIB, prepared the other vehicle data for the study. Mr. D. A. Sloss, Stevens Institute of Technology, and Mr. Lynn A. Martin, TACOM, supervised preparation of much of the linear terrain data required and all of the

linear-feature-crossing-time assessments. The report was prepared by Messrs. Nuttall and Randolph.

COL G. H. Hilt, CE, was Director of WES during the conduct of the study and the preparation of the report. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, METRIC (SI) TO U. S. CUSTOMARY AND U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
	Metric (SI) to U. S. Customary	
millimetres	0.03937	inches
centimetres	0.3937	inches
metres	3.2808	feet
kilometres	0.6214	miles (U. S. statute)
square kilometres	0.3861	square miles
grams per cubic centimetre	62.43	pounds per cubic foot
metres per second	3.2808	feet per second
	U. S. Customary to Metric (SI)	
inches	2.54	centimetres
feet	0.3048	metres
yards	0.9144	metres
miles (U. S. statute)	1.609344	kilometres
square inches	6.4516	square centimetres
square miles	2.59	square kilometres
gallons	3.785×10^{-3}	cubic metres
pounds (mass)	0.45359237	kilograms
tons (mass)	907.185	kilograms
pounds (force)	4.448222	newtons
kips (force)	4.448222×10^{-3}	newtons
pounds (force) per square inch	6894.757	pascals
miles per hour	1.609344	kilometres per hour
horsepower	745.6999	watts
degrees (angle)	0.01745329	radians

MOBILITY ANALYSES OF STANDARD- AND HIGH-MOBILITY TACTICAL SUPPORT VEHICLES (HIMO STUDY)

PART I: INTRODUCTION

Background

1. The work reported herein was performed in support of the U. S. Army Training and Doctrine Command (TRADOC) study, "Special Analysis of High-Mobility Vehicles" (short title, HIMO Study). The objectives of the TRADOC HIMO Study are to:[1]

   a. Determine future requirements for high-mobility vehicles in the Army inventory.

   b. Determine the comparative effectiveness of high-mobility and standard-mobility (tactical) vehicles in combat support.

   c. Demonstrate tactical fleet compositions best suited for various terrain and weather conditions and types of conflict.

2. Originally these questions were to be examined by means of a two-brigade troop test to be conducted during the summer of 1973.[2] In reviewing the plan during the fall of 1972, personnel of the U. S. Army Combat Developments Command, the Department of the Army (DA), the U. S. Army Materiel Command (AMC), and the AMC Mobility Research Community [U. S. Army Tank-Automotive Command and the U. S. Army Engineer Waterways Experiment Station (TACOM and WES)] agreed that the proposed troop test would not provide the required data, primarily because results would reflect the influences of only a single terrain and one chance set of weather conditions.[1] An alternative approach was proposed based upon use of the AMC Mobility Model (AMM)[3,4,5] to develop basic vehicle performance data in several terrains and weather conditions, doing tasks determined by means of scenario map play.

Basic HIMO Study Methodology

3. The alternative approach was accepted and expanded by the Combined Arms Concepts Developments Agency of TRADOC and, subsequently,

by the TRADOC Logistics Center and TRADOC Transportation School. As developed by these TRADOC elements, the methodology was to:

a. Select scenarios and terrains to exercise tactical high-mobility* and tactical standard-mobility vehicles in the brigade area in various combat postures.

b. Play scenarios on 1:50,000 maps to develop detailed missions required in support of two mechanized brigades. (Place combat units and resupply points for a given day of battle and a given posture. Delineate appropriate on- and off-road routes over which combat support vehicles would be expected to maintain supply flow to the combat units and over which various other typical combat support missions would be conducted. Repeat the map play for as many days of battle, postures, scenarios, and areas as needed.)

c. Generate required resupply routes for each unit in each location and posture during the map play.

d. Use AMM to make vehicle- and terrain-specific engineering predictions of vehicle on- and off-road travel performance in the conduct of all missions in each scenario, each under several weather conditions and degrees of route denial.

e. Use the government-owned Tactical Vehicle Fleet Simulation (TVFS), resident on the computers at General Research Corporation (GRC), to integrate the AMM travel time predictions with maintenance and depot times, resupply demands of the units in various combat postures and intensities, Reliability, Availability, Maintainability-Durability (RAM-D) considerations, and vehicles available to each unit (based on standard and proposed Tables of Organization and Equipment for the standard and HIMO vehicle fleets), and to predict various measures of the relative "combat potential" of the two fleets.

f. Analyze AMM and TVFS simulation results, along with tactical and cost considerations, to answer the study questions.

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* Tactical high mobility. The highest level of mobility designating the requirements for extensive cross-country maneuverability characteristic of operations in the ground-gaining and fire-support environment.
Tactical standard mobility. The second highest level of mobility designating the requirment for occasional cross-country movements.
Tactical support mobility. A level of mobility designating the requirement for infrequent off-road operations over selected terrain with the preponderance of movement on primary and secondary roads.[1]

Objectives of WES-TACOM Activities in Support of HIMO Study

4. Application and extension of AMM to implement the HIMO Study was assigned by TRADOC to the AMC mobility research team at WES and TACOM. The objectives of the resulting work reported herein were to:

a. Provide for use in TVFS engineering predictions of individual vehicle on- and off-road travel times over designated routes in terrain and weather conditions peculiar to the selected study areas.

b. Make an independent assessment of the compatibility of individual vehicle mobility performance with terrain and mission demands, based upon statistical characterizations of performance in the study areas generally.

Scope of AMC Mobility Research Team Activities

5. Activities required of the AMC mobility research team to accomplish its objectives and their relation to other elements of the study are shown in the flow chart (Figure 1). Principal AMC activities were:

a. Preparation of areal terrain data for the selected study areas (WES).

b. Preparation of linear-feature-crossing terrain data (rivers, streams, canals, embankments, etc.) (TACOM and WES).

c. Preparation of vehicle data (WES).

d. Extraction of terrain and road data for all job travel routes (WES).

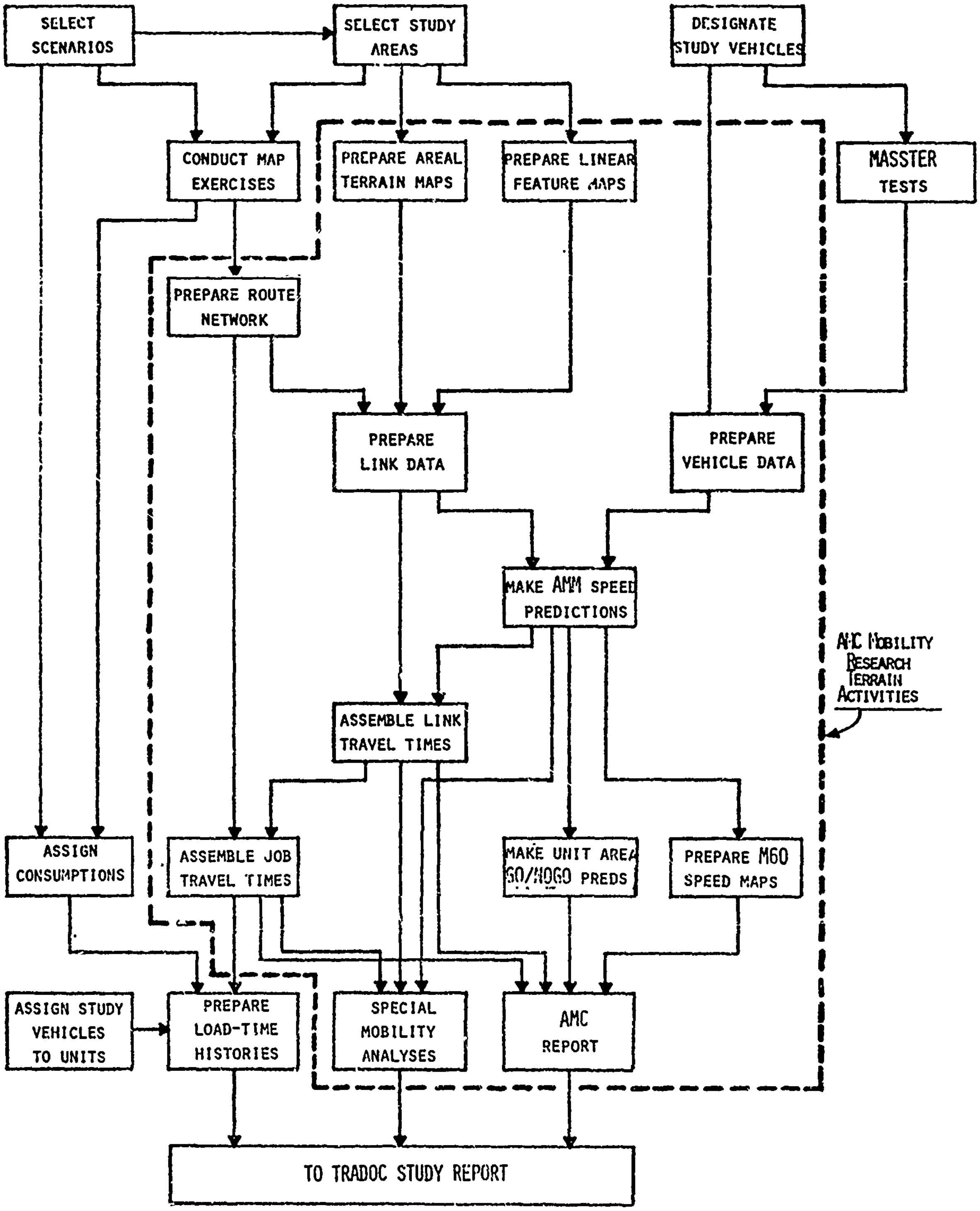
e. Prediction with AMM of areal terrain and on-road single vehicle, one-pass speeds (WES).

f. Assessment with AMM of linear-feature-crossing times (TACOM).

g. Aggregation of vehicle speed and route data to job travel times on designated missions in a form suitable for use in TVFS (WES).

h. Preparation of special statistical and subsidiary analyses and reporting (WES).

Important elements of the detailed methodology involved are discussed in appendices as follows: Appendix A, "Brief Description of the AMC Mobility Model (AMM) as Used in the HIMO Study;" Appendix B, "Terrain



* MASSTER - Modern Army Selected Systems Test Evaluation and Review

Figure 1. AMC activities in support of TRADOC HIMO Study

Mobility Map Preparation;" Appendix C, "Preparation of Link Data;" Appendix D, "Statistical Examinations of Individual Vehicle Performance in the two HIMO Study Areas;" Appendix E, "Computation of a Mission-Oriented Average Speed Based on a Statistical Mission Definition and Vehicle Performance Statistics for an Area and a Condition;" Appendix F, "Data Used to Characterize Study Vehicles for Prediction With AMM;" and Appendix G, "Participants in Scenario Exercises."

6. Products resulting from these activities are:

   a. Travel time predictions for each vehicle in each designated mission or job in each study area, under three basic seasonal (or terrain) conditions and over three different routes, to support fleet simulations using TVFS.

   b. Special analyses of individual vehicle performance in areal terrain occupied by combat units (as designated by scenario map play) to examine vehicle capabilities for supporting combat units in place.

   c. Maps showing the predicted speed in areal terrain of the M60A2 combat tank under wet-season conditions, to summarize approximately the terrain mobility conditions within each study area in readily comprehensible terms.

   d. Statistics relating individual vehicle performance to the terrain in each study area, as a basis for an independent, general assessment of vehicle-terrain-mission compatibility.

   e. This report, which outlines and discusses the methods used to develop the data and summarizes the above statistics and the assessments which grow from them.

7. Travel times for each vehicle in individual mission performance, for use in TVFS, were forwarded to GRC on magnetic tape during the period January-March 1975. Hard copy is available at WES, and statistics derived from these predictions are presented herein (Appendix D). Intermediate results are also available at WES as follows:

   a. Areal and linear terrain mobility maps (as computer arrays) digitized to 105.83- by 127-m* cells. The cell size was selected to facilitate rapid map printing (see Appendix B, paragraph 3).

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* A table of factors for converting metric (SI) units of measurement to U. S. customary units and U. S. customary units to metric (SI) units is given on page 10.

b. Composite route overlay maps for each study area, which delineate all travel routes developed in the map play and identify all nodes and links* throughout the resulting network by means of which job travel routes are identified in subsequent computations.

c. Link data files, which characterize each link in terms of all nominally uniform on- and off-road and linear feature segments of which it is comprised.

d. Areal and road unit speed predictions and linear-feature-crossing-time assessments from AMM for all study vehicles in every road or terrain unit encountered on all links in each study area.

e. Link travel times for every vehicle on every link under all conditions with each link considered both "as-is" and as an off-road traverse (paragraph 28).

8. A small sample of the M60A2 areal terrain speed maps is included in this report (paragraphs 48 and 49). Copies of the complete computer maps for both areas in the form of 1:50,000 overlays were supplied to TRADOC separately.

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* The following special definitions are used in further discussion:

Job: The route connecting a unit with a supply point of the route joining two consecutive positions of a unit (paragraphs 23-27).
Node: Route intersection or end point.
Link: The route joining two nodes.
Segment: Nominally uniform subsection of a link.

PART II: STUDY PARAMETERS

Vehicles in the Study

9. Vehicles in the study were designated by TRADOC as follows:

High-mobility vehicles:

- M561, 1-1/4-ton GAMA GOAT, 6x6
- M656, 5-ton truck, cargo, 8x8
- M520E1, GOER, 8-ton truck, cargo, 4x4
- M559, GOER, 2500-gal truck, tanker, 4x4
- M553, GOER, 10-ton truck, wrecker, 4x4
- M548E1, 5-ton carrier, cargo, tracked

High-mobility and standard vehicle:

- M151A2, 1/4-ton truck, utility, 4x4

Standard-mobility vehicles:

- M715E1, 1-1/4-ton truck, cargo, 4x4
- M35A2, 2-1/2-ton truck, cargo, 6x6
- M49A2C, 2-1/2-ton truck, FS (1200/600 gal) 6x6
- M813, 5-ton truck, cargo, 6x6
- M821, 5-ton bridge transport, 6x6
- M816, 5-ton truck, wrecker, 6x6
- M125E1, 10-ton truck, cargo, 6x6
- M818, 5-ton truck, tractor, 6x6, with M127A1C, 12-ton semitrailer

Special high-mobility excursion vehicle:

- Twister Dragon Wagon 901 (TDW901), 8-ton cargo, 8x8

Reference vehicle:

- M60A2, tank, combat, full tracked

10. All 17 vehicles are actual hardware items. It is to be noted that the vehicles in the standard-mobility fleet and the M151A2 1/4-ton, 4x4, represent 1950 technology, and those in the high-mobility fleet represent early 1960 technology. The single, special, high-mobility excursion vehicle, the Twister Dragon Wagon (TDW901), may be considered to represent early 1970 technological possibilities.

Vehicle characteristics

11. All vehicles were characterized as carrying their rated payloads and operating at recommended off-road tire inflation pressures (or sand pressures, as appropriate). Principal characteristics of all of the vehicles are summarized in Table 1, and complete vehicle data as required for input to AMM are given in Appendix F.

Special tests by Project MASSTER

12. Both field experience and simulations have shown that dynamic responses of vehicles traversing rough terrain and crossing minor obstacles have a strong influence on actual vehicle speed performance. AMM is so structured that values for these critical vehicle characteristics may be those determined by means of dynamics simulations or from experimental data. To ensure that the dynamic response characterization of all study vehicles, in the terms required by AMM, was as realistic and consistent as possible, this characterization was in all cases (except for the M125E1, 10-ton, 6x6) based upon experimental data, some of which were developed in special dynamics tests conducted by WES for Project MASSTER at Fort Hood, Texas.[6] The required dynamic response data for the M125E1 were developed by means of the two-dimensional vehicle dynamics simulation, which is available as a module of AMM.[7,8]

Scenarios, Study Areas, and Conditions

13. Two study areas, each about 3000 sq km, were selected by TRADOC, one in the Mid-East and the other in West Germany. Missions for these areas were detailed in accordance with selected portions of authorized TRADOC study scenarios.

Seasonal weather conditions

14. Vehicle performance was predicted for each area under two weather and climatic conditions:

a. Dry season; generally most favorable for vehicle mobility (except possibly for dust conditions, which do not significantly affect single-vehicle speeds and are accordingly not included in the AMM predictions)

b. Wet season, raining; generally the worst condition for vehicle mobility because of high soil moisture contents

Table 1

Summary of Vehicle Characteristics and Some Performance Parameters

Vehicle	Gross Vehicle Weight lb	Wheel Base in	Power to Rate Ratio hp/t	Ground Clearance* in.	Approach Angle Deg	Departure Angle Deg	Wheel Spacing in	VCI_1 Fine-Grained	VCI_1 Coarse-Grained	Max Speed mph	Speeds for Obstacle Heights at 2.5 g: 2 in.	6 in.	10 in.	Six Watt Cross-Country Speeds for rms in in.: 1	2	3	Six Watt Road and Trail Speeds for rms in in.: 1	2	3
M561, 1-1/4-Ton GAMA GOAT, 6x6	9,172	81.0	22.5	15.0	62.5	32.0	81	19	12	55	100	18.0	8.0	15.5	11.5	7.5	23.5	10.6	3.0
M656, 5-Ton Truck, Cargo, 8x8	25,835	148.0	16.3	20.0	50.0	61.5	90	20	14	50	50	22.3	9.7	17.3	10.0	10.0	26.2	11.8	9.2
M520E1, GOER, 8-Ton Truck, Cargo, 4x4	43,210	235.0	9.9	29.0	35.0	35.0	235	36	8	30	100	34.0	4.0	8.8	6.0	6.0	15.0	8.0	6.0
M559, GOER, 2500-Gal Truck, Tanker, 4x4	46,370	235.0	9.2	29.7	35.0	35.0	235	42	8	30	100	34.0	4.0	9.0	6.0	6.0	15.0	8.0	6.0
M553, GOER, 10-Ton Truck, Wrecker, 4x4	46,540	235.0	9.2	29.3	35.0	35.0	235	42	8	30	100	34.0	4.0	9.0	6.0	6.0	15.0	8.0	6.0
M548E1, 5-Ton Carrier, Cargo, Tracked	26,450	NA	15.3	16.0	57.0	35.0	NA	16	0	40	100	40.0	7.0	15.0	10.0	9.0	21.8	11.2	9.0
M151A2, 1/4-Ton Truck, Utility, 4x4	3,200	85.0	44.4	12.7	66.0	37.0	85	19	23	65	100	100.0	12.0	21.0	9.0	5.0	26.0	11.0	5.0
M715E1, 1-1/4-Ton Truck, Cargo, 4x4	8,400	126.0	27.6	15.5	45.0	25.0	126	33	17	60	100	200.0	6.0	13.0	9.5	7.0	16.0	8.5	6.0
M35A2, 2-1/2-Ton Truck, Cargo, 6x6	19,300	154.0	14.5	19.1	40.0	40.0	130	30	17	56	100	37.0	13.0	16.6	10.0	8.0	23.5	10.5	4.8
M49A2C, 2-1/2-Ton Truck, FS(1200/600 Gal)6x6	20,025	154.0	14.0	19.0	40.0	40.0	130	42	18	56	100	37.0	13.0	16.6	10.0	8.0	23.5	10.5	4.8
M813, 5-Ton Truck, Cargo, 6x6	32,544	179.0	16.3	22.5	35.0	39.0	152	35	15	52	100	40.0	7.0	17.0	9.0	7.0	20.0	13.0	7.0
M821, 5-Ton Bridge Transport, 6x6	39,280	215.0	12.7	22.5	37.5	26.0	187	29	21	52	100	40.0	7.0	17.0	9.0	7.0	20.0	13.0	7.0
M816, 5-Ton Truck, Wrecker, 6x6	43,329	179.0	11.5	22.5	35.0	38.0	152	56	14	52	200	40.0	7.0	17.0	9.0	7.0	20.0	13.0	7.0
M125E1, 10-Ton Truck, Cargo, 6x6	51,630	181.5	11.6	26.0	30.0	45.0	139.5	42	18	42	100	40.0	7.0	17.0	9.0	7.0	20.0	13.0	7.0
M818, 5-Ton Truck, Tractor, 6x6 with M127A1C, 12-Ton Semitrailer	58,930	167.0	8.5	23.0	45.0	70.0	140	40	34	50**	44	13.0	7.3	11.0	8.0	6.5	23.0	10.0	8.0
Twister Dragon Wagon 901 (TDW901), 8-Ton, Cargo, 8x8	38,990	160.0	11.5	34.0	55.0	65.0	102	26	8	56	55	48.0	18.2	20.7	12.0	12.0	27.9	16.3	15.3
M60A2, Tank, Combat, Full Tracked	104,000	NA	15.0	18.0	90.0	42.5	NA	21	0	30	60	60.0	12.5	44.0	20.0	13.0	44.0	20.0	13.0

* Minimum ground clearance between innermost wheels.
** Maximum recommended cross-country towing speed is 20 mph for the trailer.

and associated reduced soil strengths and because of potential slipperiness on soil strengths that would otherwise be adequate for vehicle flotation and traction.

In wet and rainy conditions, referred to hereafter simply as the wet (study) condition, soil-surfaced trails were considered to be deteriorated by soil moisture and slipperiness, and maximum available traction on superhighways and primary roads was reduced from the normal, nominal value of 70 percent of the weight on powered axles to 55 percent and on secondary roads from 60 to 50 percent. General visibility conditions were assumed unchanged (light rain). Visibility distances in vegetation were assigned according to the period of the year in which the wet or dry soil conditions occurred, based upon rainfall records for each area. Tire chains were not used on wheeled vehicles in slippery conditions, and the two tracked vehicles (M548E1 and M60A2) were considered to be operating with their normal track road pads in place.

Sand terrain

15. In the Mid-East area, predictions were made for a third condition in which the actual terrain was arbitrarily converted to an all-sand terrain with sand dunes by

a. Converting all actual soils to dry desert sands with appropriately reduced strengths.

b. Doubling all slopes to a maximum of 60 percent (the approximate angle of repose of dune sands, frequently found on the lee side of desert dunes).

Characteristics of all roads and trails were unchanged, except that the soil-surfaced trails were assumed to be trails in sand. These changes are considered reasonable for an exploration of vehicle and fleet performance in large expanses of dune terrain, but the actual configuration of the terrain and roads is, of course, entirely synthetic.

Snow-covered terrain

16. In the West Germany area, a third condition for which predictions were made was terrain uniformly covered by 10 in. of dry snow, which is a reasonable maximum average depth for the actual area. Differences in snow depth or characteristics due to forests, drifting, slope orientation to the suns rays due to winds, etc., were not played.

Ground beneath the snow was assumed to be frozen (a present AMM modeling limitation) so that although the snow depth is a reasonable worst condition (except for drifts), the overall condition is not as bad as it might have been with weak, unfrozen soils beneath. Stream-crossing predictions associated with the snow condition, however, were based on wet soil conditions on the banks, and consistent with this, no frozen waterways were played. Trails were assumed to be snow covered. To reflect approximately the effect of traffic and snow removal as a function of road class, maximum traction on superhighways was assumed to be reduced to 55 percent, on primary roads to 50 percent, and on secondary roads to 30 percent. Wheeled vehicle performance was predicted without tire chains; tracked vehicle performance, with normal track road pads fitted.

Route Options for Job Performance

17. For each area and each condition, job or mission predictions were made on the basis of three possible travel routes connecting the mission end points (units and supply points or successive unit positions). The first route was along the Main Supply Route (MSR) as designated in the scenario map exercise; and the second was a secondary route, chosen during the map play, that was largely roads and trails not a part of the MSR network. A third route was created by converting the MSR on-road link closest to the forward edge of the battle area to an off-road traverse along a path a short distance to one side of the road. The last two routes were introduced to examine the effects of some MSR interdiction and of two kinds of response, extensive rerouting and direct off-road bypassing.

PART III: OVERVIEW OF STUDY ACTIVITIES

18. Major study activities identified in Figure 1 are reviewed briefly in the following paragraphs, with emphasis on WES-TACOM activities (enclosed in the figure by the heavy dashed line box). Further elaboration of several aspects of the work will be found in the appendixes.

Study Map Preparation

19. Once the study areas were designated, work began by the WES-TACOM team on preparing maps of the terrain (Appendix B) in the multidimensioned engineering terms needed to make the AMM predictions. The detail required by AMM and the large areas involved made this a formidable task. A major part of the WES-TACOM effort went into developing and mapping these critical data. Two basic series of maps were prepared--one dealing with the areal terrain and the other dealing with linear features, i.e. potential barriers such as rivers, ditches, and embankments. WES prepared the areal terrain maps and WES and TACOM worked together to prepare the linear feature maps.

20. The resulting maps of the areal terrain units for the study areas are considered to be study maps. Specific values for the many terrain factors involved were largely inferred from available qualitative data sources interpreted in context of local climate, cultural practices, etc., but no ground truth (in the full meaning of the term) was used. As a result, it cannot be guaranteed that the specific set of factor values assigned to a given point on a map will, in fact, be found at that point on the ground. It can be claimed, however, that the maps are consistent with the available information. For example, if source data indicated a forest over some area, appropriate vegetation attributes were included in the terrain unit descriptions that cover that area. It can also be asserted that the area as mapped is generally representative of the levels and areal distribution of those factors that influence vehicle mobility performance throughout the area as a whole.

21. The final maps are stored in separate computer arrays that identify the areal and linear terrain factor values (including temporal variations) associated with each 105.83- by 127-m cell over all of each study area (over 200,000 cells per study area). All further computations requiring terrain data draw information from these maps directly in the computer. Figure 2 shows a portion of a 1:50,000 areal terrain unit map as printed out by the computer. Each pair of alphanumeric symbols identifies a terrain cell in terms of the terrain unit that describes it. Three-digit numeric interpretations of the two-character symbols and patch boundaries were added manually to illustrate that discrete areal patches identified by a single terrain unit number are generally of a size to contain many cells.

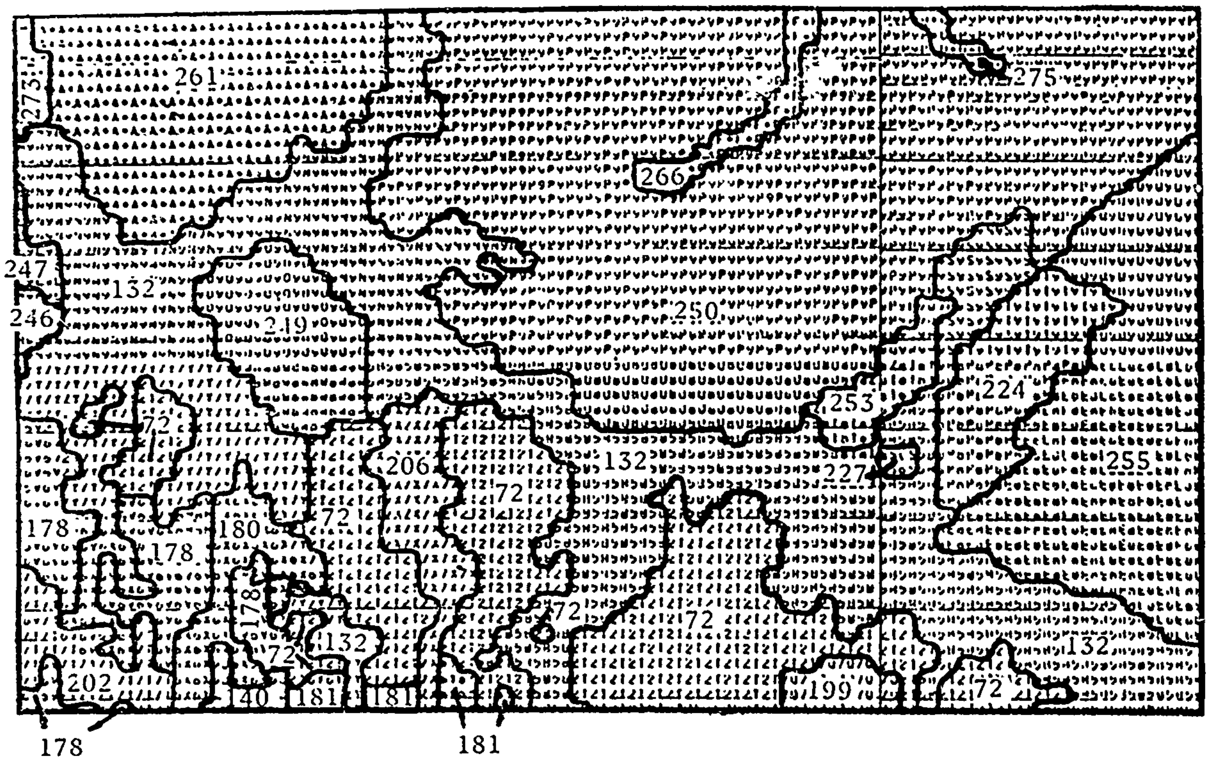
Scenario Map Play

22. Personnel from TRADOC schools and study agencies assembled for two one-week working sessions at which the Mid-East and West Germany scenarios, respectively, were played on 1:50,000 topographic maps. Appendix G lists the participants. The TRADOC teams selected a number of specific days within each scenario representative of defense, attack, and delay operations. For each day, personnel from appropriate schools or agencies indicated on a map overlay the areas occupied by all combat and support elements identified in the scenario and designated supply delivery points to each unit. They then indicated appropriate MSR's and secondary supply routes between each combat unit and concurrent points of supply. Figure 3 shows an example. In a second set of overlays, similar routes were designated for a number of typical moves by combat and support units.

Route Network Map Preparation

Method of preparation

23. At the conclusion of map play for each of the two study areas, the designated routes for all days and all units were overlaid by WES to form a single composite route network map, and all on-road and on-trail



NOTE: Large numbers indicate terrain unit numbers.
Terrain unit boundaries were drawn manually.

Figure 2. Final digitized terrain unit map

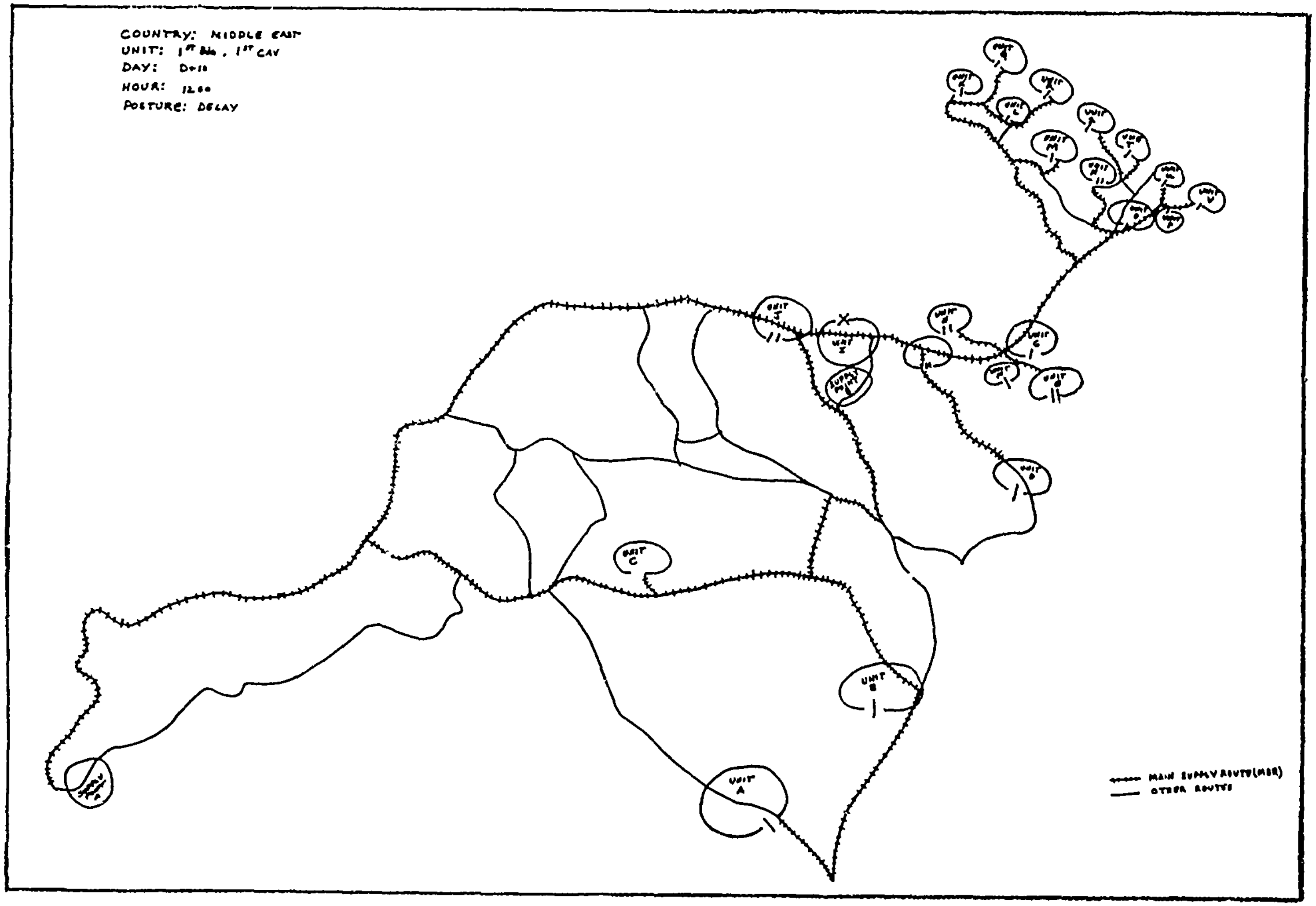


Figure 3. Sample working overlay from scenario play

routes were carefully adjusted to match roads and trails as shown on the base topographic maps. At this stage, the routes were segmented according to route type (superhighway, primary or secondary road, trail, or off road), and each segment was appropriately coded. Linear features crossed, whether bridged or not, were mapped. All route intersections and job end points, termed nodes (footnote of paragraph 7), were numbered for future identification. Figure 4 shows, at much reduced scale, approximately 60 percent of the resulting composite route network map for the West Germany study area. Figure 5 is a small part, at actual map scale (1:50,000), of the composite network map for the Mid-East study area and shows the level of information contained in the composite route network overlays.

24. Table 2 summarizes some of the characteristics of the two composite route networks. Because of the high density of secondary and tertiary roads in West Germany, very little off-road operation is required except under the impact of enemy action.

Job definition

25. Once the network for an area was completed and all nodes were numbered, the two resupply routes (MSR and secondary) connecting each unit on a given scenario day with concurrent resupply points for various classes of supply were defined. Complete resupply routes, termed jobs, were identified by their end point nodes (code number for unit delivery point location, plus code number for resupply point location). Two lists of intermediate connecting nodes were made to define each job, one for the MSR and one for the secondary route. The on-road or on-trail link in the MSR closest to the unit being supplied was flagged at this time for subsequent conversion to an off-road traverse which defined the third route option (interdiction responded to by direct off-road bypassing, paragraph 17). Table 3 shows a sample job specification list. Combat or support element moves developed in the scenario play were similarly defined and specified in a separate file.

26. Table 4 summarizes some of the characteristics of the job routes. Note that in arriving at the total and average one-way job distances shown, each job is considered only once, i.e., there is no

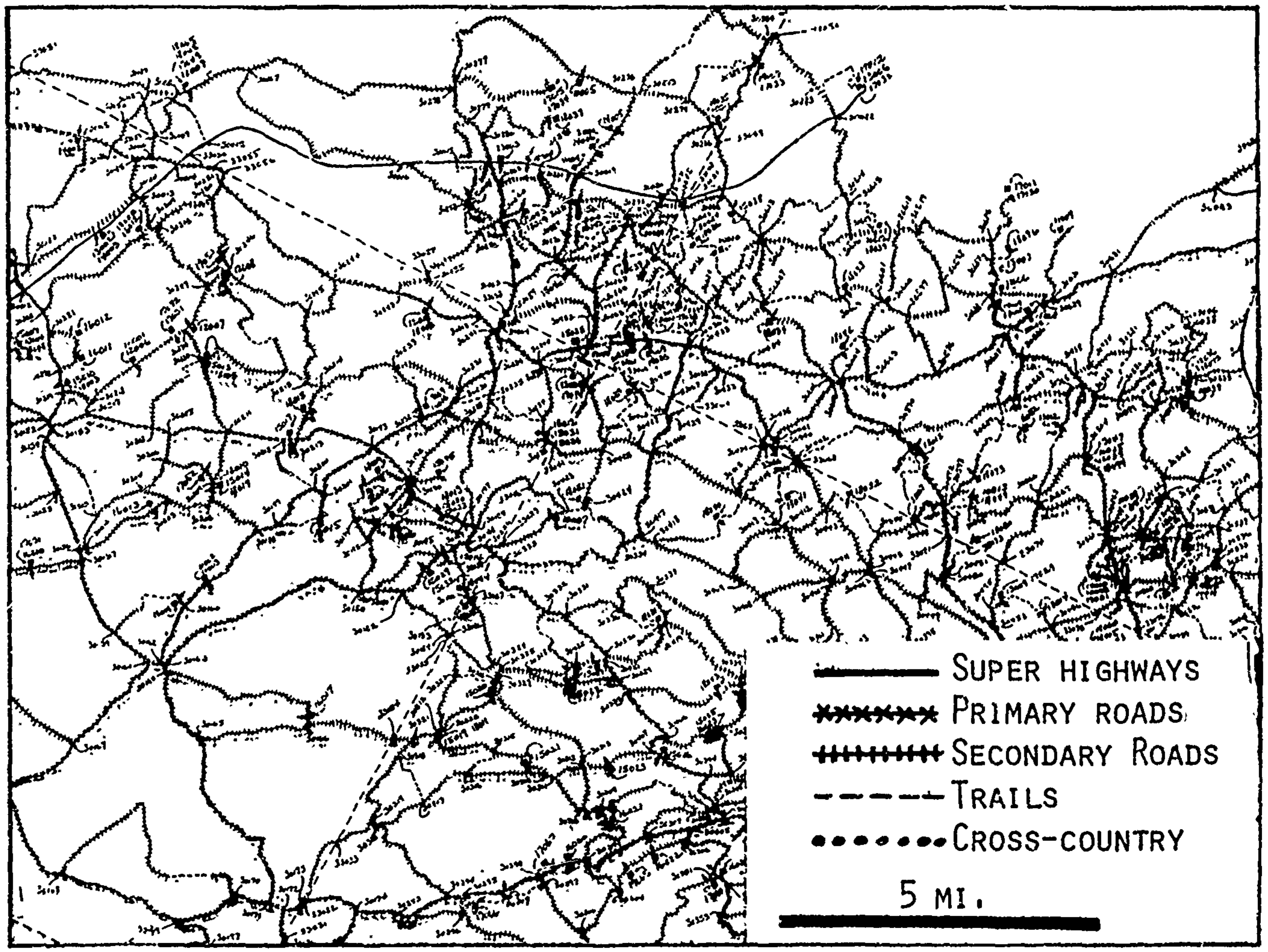


Figure 4. Partial supply route network map for West Germany study area

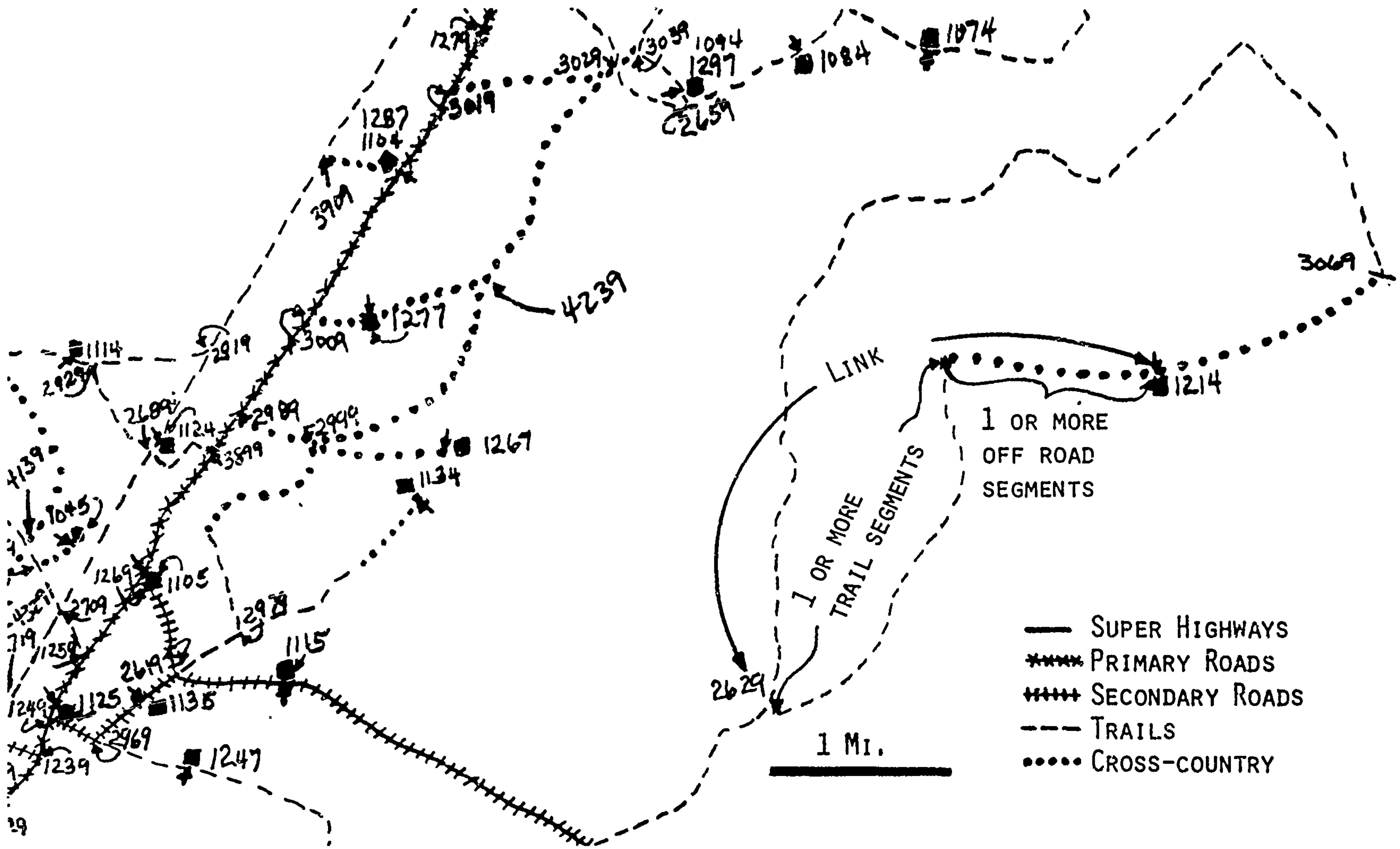


Figure 5. Sample of route network for Mid-East study area

Table 2

Characteristics of Composite Route Networks

Study Area Features	Mid-East	West Germany
Total distance, miles	533	1678
Number of links*	854	2184
Average link length, miles	0.62	0.77
Composition of as-is** Network, percent		
Superhighways	0	3.1
Primary roads	7.3	21.1
Secondary roads	29.7	61.4
Tertiary roads and trails	44.9	14.3
Off-road traverse	18.1	0.1
	100.0	100.0

* See paragraph 7b.
** See paragraph 28.

Table 3

Typical Job Specification

List of Links Defining Three Routes

Job: 2261 - 1161

Node Points	
MSR and Tertiary Route	Secondary Route
2261	2261
3809	3809
1539	1539
1549	1549
1559	1559
1569	1569
1076	1076
1066	1066
1609	1609
1629	1629
6119	6109
1639	1235
1659	2829
1241	1669
2839	2749
1689	2739
1699	1739
1194	1929
1729	1161
1989	
1171	
1929*	
1161*	

* As-is for MSR, but off road for tertiary route.

Table 4

Some Characteristics of Job Routes

Study Area Route	Mid-East		West Germany	
	MSR**	Secondary	MSR	Secondary
All jobs				
Number of jobs	245	245	434	434
Total distance*, miles	1921	2015	7607	8742
Average job distance (one way), miles	7.8	8.2	17.5	20.1
Resupply jobs (logistics)				
Number of jobs	182	182	343	343
Total distance, miles	1444	1481	6387	7435
Average job distance (one way, miles)	7.9	8.1	18.6	21.7
Unit move job (attack)				
Number of jobs	39	39	51	51
Total distance, miles	264	287	666	703
Average job distance (one way), miles	6.8	7.4	13.1	13.8
Unit move jobs (delay)				
Number of jobs	24	24	40	40
Total distance, miles	213	247	554	603
Average job distance (one way), miles	8.9	10.3	13.8	15.1

* Each job considered only once.

** Interdicted MSR job distances are the same as MSR distances.

weighting for the relative frequency with which various job routes are used during any time frame. Such weighting requires the TVFS play.

27. The simple statistics in Table 4 show that job routes in the West Germany study area were almost 2.5 times longer than those in the Mid-East study area. Use of the secondary routes increases travel distance by 15 percent in the West Germany area and 5 percent in the Mid-East area. It was observed that, because of the relatively low density of good roads in the Mid-East area, the selected MSR routes (which utilized the better roads) were actually longer for some jobs than the associated secondary routes. This, together with the shorter average job route length in the Mid-East area, accounts for the significant difference between the route elongation associated with use of the secondary routes in the two areas.

Link Data Preparation

28. The network map for each study area was overlaid in the computer on the corresponding digitized areal and linear terrain unit maps, and each link was characterized in terms of the areal and road terrain units comprising it, with related distances, and the linear terrain units that were crossed (Appendix C). Each link was characterized "as-is", i.e. as a series of road, trail, or off-road segments exactly as indicated on the network map. Road terrain units were developed at this stage from data on the network maps and on the areal terrain unit map. Each link was also characterized as a traverse completely off road along the same path, as though no roads, trails, or bridges existed. The second link characterization represents, conceptually, the condition that a vehicle would encounter if forced off the road (as by enemy action) and attempted a direct bypass by running roughly parallel to the road, but 10 to 100 m to one side.

Vehicle Data Preparation

29. Concurrent with the link data preparation, necessary engineering data on each of the study vehicles as described in para-

graphs 9-12) were assembled from many sources, checked, and prepared for use in AMM. Pertinent results of the MASSTER tests[7] to determine vehicle dynamic responses in rough terrain and obstacle crossing were integrated at this stage.

AMM Performance Predictions

30. The AMC Mobility Model (AMM) examines vehicle-driver-terrain interactions to determine the maximum feasible speed that a single vehicle, driven by a good (constant) driver, can achieve in a single, closely specified terrain situation. AMM, in its early 1974 version (AMC-74X, Appendix A), was used to make single-vehicle speed predictions in each selected seasonal and weather condition for each areal, road, or linear feature terrain unit involved in the job routes delineated in the study.

31. AMM performance predictions for each vehicle were made with the vehicle carrying its rated payload and operating at recommended off-road tire inflation (or sand operating inflation, as appropriate for the terrain) under good daylight visibility conditions. Omnidirectional areal speeds, bidirectional on-road speeds, and linear-feature-crossing times were stored in computer files for use in establishing link travel times and in developing various performance statistics. Areal terrain and on-road predictions using AMM were made by WES; linear-feature-crossing-time predictions, by TACOM.

32. Figure 6 illustrates the general form of the output of the AMM areal terrain speed prediction module. (The list shown has been ordered in an output processor in decreasing order of in-unit speeds, preparatory to developing the off-road speed profile. See Appendix A.) On-road and linear-feature-crossing predictions are stored in similar format. Over a million individual speed and crossing time predictions were made in the course of the study.

Link Travel Times

33. The composition of each link as determined in the link data

Terrain Unit	In Unit	Accum	In Unit	Accum	Speed On Slopes, mph Up	Level	Down	Factor Limiting Speed On Slopes Up	Lv	Dn
1136	0.2	54.3	7.5	10.9	7.5	7.5	7.5	10	10	10
658	0.2	54.5	7.5	10.9	6.5	8.1	8.1	6	10	10
681	0.1	54.6	7.5	10.9	7.5	7.5	7.5	8	8	8
522	0.1	54.7	7.5	10.9	4.4	11.3	11.3	6	5	5
873	0.1	54.8	7.5	10.9	7.5	7.5	7.5	5	5	5
453	0.1	54.9	7.5	10.9	7.5	7.5	7.5	5	5	5
160	0.1	54.9	7.5	10.9	7.5	7.5	7.5	10	10	10
248	0.1	55.0	7.5	10.9	7.4	7.5	7.5	9	8	8
605	0.1	55.1	7.5	10.9	5.0	10.0	10.0	6	5	5
1427	0.	55.1	7.5	10.9	6.8	8.0	8.0	6	5	5
955	0.	55.1	7.5	10.8	7.4	7.6	7.6	10	10	10
173	0.	55.2	7.5	10.8	7.5	7.5	7.5	5	5	5
636	0.	55.2	7.5	10.8	5.0	10.0	10.0	6	5	5
1558	0.	55.2	7.5	10.8	7.5	7.5	7.5	8	8	8
225	0.	55.2	7.5	10.8	7.5	7.5	7.5	10	10	10
219	0.	55.2	7.5	10.8	7.5	7.5	7.5	10	10	10
58	0.2	55.4	7.4	10.8	6.4	7.9	7.9	6	8	8
540	0.	55.4	7.4	10.8	7.2	7.5	7.5	10	10	10
615	0.	55.4	7.4	10.8	6.4	8.0	8.0	9	5	5
1323	0.	55.4	7.4	10.8	6.5	7.9	8.0	10	10	10
411	0.	55.4	7.4	10.8	7.1	7.5	7.5	6	5	5
1102	0.1	55.6	7.3	10.8	7.3	7.3	7.3	8	8	8
218	0.1	55.7	7.3	10.8	6.8	7.6	7.6	10	10	10
834	0.1	55.7	7.3	10.8	7.3	7.3	7.3	5	5	5
1165	0.1	55.8	7.3	10.8	5.4	9.0	9.0	6	5	5
1398	0.	55.8	7.3	10.8	7.3	7.3	7.3	5	5	5

Off-Road Terrain Unit No.

Distance In-Unit

Basic In-Unit and Accumulative Speed Predictions (mph)

Reasons For NOGO or Speed Limit

Figure 6. Partial listing of cross-country speeds in terrain units (M151A2)

analysis was matched with the relevant speed predictions from AMM to assemble data for determining total one-way travel time for each vehicle on each link (both as-is and as an off-road traverse) under each of three conditions (paragraphs 14-16). Link travel times were established by simply adding segment travel times and linear-feature-crossing times. Segment travel times were determined from segment distances, and the associated omnidirectional or bidirectional speeds predicted by AMM (Appendix A, paragraphs 12 and 25). No acceleration or decleration effects across terrain unit boundaries were incorporated,* and resulting link times and speeds were not specific to one direction of travel or the other over a given link (Appendix A, paragraph 46).

34. Table 5 illustrates the data as assembled for two links in the as-is condition. Data assembled for each vehicle-condition-link characterization at this stage were:

a. Total link distance, miles

b. Total predicted one-way travel time over the link in areal and road terrain that was GO, min.

c. Total areal or on-road NOGO distance within the link, miles

d. Total linear-feature-crossing time assessed for the link, min

NOGO distances and linear-feature-crossing times were merged to single, overall link travel times only when the job travel times were assembled.

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* When the predicted maximum speed in adjacent segments is greatly different, vehicle acceleration or deceleration must take place somewhere in the neighborhood of the boundary. Similar acceleration and deceleration usually take place when a vehicle is approaching and departing from a linear feature crossing. Simply summing segment travel times ignores this effect. Validation testing in the field and computations have both shown that this is a source of consistent overestimation of actual traverse speeds. Except in the case in which the vehicle fleet being evaluated includes machines with highly different power densities, however, the effect of ignoring this acceleration and deceleration is essentially evenhanded, overestimating speeds by an average of approximatley 5-10 percent. It would have been technically possible to incorporate acceleration and deceleration in the present predictions, but the required computer times and storage would have been more than doubled. Neither resources nor time permitted such expansion, and this refinement was not considered to be essential for the purposes of this study.

Table 5

Example of Link Time Predictions for Two Links, As-Is Condition

(GO - Min, NOGO - Miles, and Linear Features - Min)

LINK 11013- 33121 DISTANCE 0.92 MILES

AS-IS*

VEHICLE	DRY			WET			SNOW		
#	GO	NG	LF	GO	NG	LF	GO	NG	LF
1	2.7	0.	0.	2.9	0.	0.	3.8	0.	0.
2	2.8	0.	0.	3.0	0.	0.	3.9	0.	0.
3	3.3	0.	0.	3.5	0.	0.	4.6	0.	0.
4	3.3	0.	0.	3.5	0.	0.	4.6	0.	0.
5	3.3	0.	0.	3.5	0.	0.	4.6	0.	0.
6	2.8	0.	0.	3.0	0.	0.	3.7	0.	0.
7	2.6	0.	0.	2.9	0.	0.	3.9	0.	0.
8	2.9	0.	0.	3.1	0.	0.	4.2	0.	0.
9	2.9	0.	0.	3.1	0.	0.	4.8	0.	0.
10	2.9	0.	0.	3.1	0.	0.	4.9	0.	0.
11	2.8	0.	0.	3.0	0.	0.	5.1	0.	0.
12	2.9	0.	0.	3.1	0.	0.	6.0	0.	0.
13	2.9	0.	0.	3.1	0.	0.	6.2	0.	0.
14	3.0	0.	0.	3.2	0.	0.	5.2	0.	0.
15	3.3	0.	0.	3.5	0.	0.	8.2	0.	0.
16	3.1	0.	0.	3.3	0.	0.	4.2	0.	0.
17	3.0	0.	0.	3.2	0.	0.	3.9	0.	0.

LINK 11013- 33120 DISTANCE 1.96 MILES

AS-IS*

VEHICLE	DRY			WET			SNOW		
#	GO	NG	LF	GO	NG	LF	GO	NG	LF
1	3.7	0.	0.	4.0	0.	0.	5.3	0.	0.
2	4.5	0.	0.	4.7	0.	0.	5.9	0.	0.
3	6.9	0.	0.	6.4	0.10	0.	8.8	0.	0.
4	7.2	0.	0.	6.8	0.10	0.	9.2	0.	0.
5	7.2	0.	0.	6.8	0.10	0.	9.2	0.	0.
6	4.5	0.	0.	4.7	0.	0.	4.9	0.	0.
7	3.9	0.	0.	4.1	0.	0.	5.4	0.	0.
8	5.1	0.	0.	5.4	0.	0.	7.1	0.	0.
9	5.0	0.	0.	5.3	0.	0.	9.0	0.	0.
10	5.1	0.	0.	5.4	0.	0.	9.3	0.	0.
11	4.4	0.	0.	5.3	0.	0.	10.6	0.	0.
12	4.9	0.	0.	5.8	0.	0.	12.8	0.	0.
13	4.9	0.	0.	4.8	0.10	0.	13.4	0.	0.
14	5.1	0.	0.	5.0	0.10	0.	10.8	0.	0.
15	7.0	0.	0.	6.7	0.10	0.	12.6	0.71	0.
16	5.8	0.	0.	6.1	0.	0.	7.1	0.	0.
17	5.3	0.	0.	5.7	0.	0.	5.4	0.	0.

* Similar predictions made for off-road link.

Maintaining their separate identities in the link time files made the files useful as well for various statistical examinations of the performance data.

Job Travel Times

35. The final basic product of all the WES-TACOM effort, required for the TVBS simulations, was the set of predictions for each study area of one-way travel time for each vehicle on each job over each of three routes and under each of three conditions. Using the link travel times, the one-way travel time for each job was assembled in the computer, essentially by summing travel times for all links identified in the job definition list (paragraph 25).

Delays due to NOGO terrain units

36. In determining total travel time for a job, however, delays had to be assigned for NOGO conditions encountered on roads and trails and in areal terrain. In addition, although the time assessed to cross any single linear feature encountered was limited to 60 min (Appendix A, paragraph 21), recurring crossing difficulties required consideration of special rules.

37. No terrain- and equipment-dependent engineering model similar to AMM exists by means of which the time required for vehicle recovery or to accomplish needed assistance by engineer troops can be predicted. As a result, the travel time losses due to NOGO situations had to be assigned on an arbitrary basis.

38. Limited WES field tests have shown that in moderately severe immobilizing areal terrain conditions, it takes about 1 hr for a single normal military vehicle to cover 200 yd (i.e., a forward speed of 0.1 mph can be achieved) using the resources of its crew, on-board pioneer tools, and winch where possible. In the absence of more definitive data, this speed was adopted for purposes of the 1972 DA WHEELS study[9] (and is still used to develop both on- and off-road speed profiles for individual vehicles--Appendix A).

39. This time loss is a severe penalty due to the 0.1-mph speed, which was judged inappropriate in relation to reasonably conducted

multivehicle Army operations. Consultation with experienced officers at the Transporation School confirmed this judgment and produced the estimate that a vehicle in a NOGO situation should not, on the average, have to wait for assistance in a given location for more than 2 hr.

40. In consideration of the fact that job routes would in general be used many times, this maximum time loss was reduced to 1 hr within any given link (average link distance in the Mid-East study area is 0.62 miles; in West Germany, 0.77 miles). The rationale for reducing the maximum wait was that, although the first vehicle might be delayed by 2 hr or even more, the problem having been thereby identified, field fixes, bypasses, or prestationed assistance would be arranged for subsequent vehicles. Succeeding vehicles over the same general route would then be delayed less (perhaps very little). Rather than elaborate this notion further without any supporting data, the 1-hr maximum time loss was accepted. The same rule was applied to linear-feature-crossing times, i.e., total linear-feature-crossing time within a single link was also limited to 1 hr. The two limits were treated independently, however, so that in a link presenting a given vehicle with both considerable NOGO distance and several difficult linear features, total job travel time could include 1 hr due to each type of trouble. This was allowed because the type of assistance or recovery effort required by each type of situation will generally be different.

Job time data

41. The job travel times as stored for further analyses contained the following information, as shown in Table 6:

a. Job travel distance over the selected route, miles

b. Total predicted one-way job travel time in areal and road terrain that was GO, min.

c. Total areal or on-road distance over the complete job route that was NOGO, miles

d. Total of single linear-feature-crossing times assessed over the complete job route, min

e. Final assigned total one-way job travel time, including linear feature crossings and NOGO's, min

Table 7 shows a small hard-copy sample of the job time data forwarded to

Table 6

Sample From Job Time Predictions File

(GO - Min, NOGO - Miles, Linear Features - Min, and Travel Time - Min)

Primary Route*

JOB 16015- 16032 DISTANCE 29.22 MILES

VEH #	DRY GO	DRY NG	DRY LF	DRY TT	WET GO	WET NG	WET LF	WET TT	SNOW GO	SNOW NG	SNOW LF	SNOW TT
1	56.4	0.	0.	56.4	61.1	0.	0.	61.1	78.3	0.	0.	78.3
2	59.5	0.	0.	59.5	63.9	0.	0.	63.9	81.4	0.	0.	81.4
3	78.0	0.	0.	78.0	82.2	0.	0.	82.2	114.6	0.	0.	114.6
4	79.2	0.	0.	79.2	83.4	0.	0.	83.4	117.4	0.	0.	117.4
5	79.3	0.	0.	79.3	83.5	0.	0.	83.5	117.4	0.	0.	117.4
6	64.0	0.	0.	64.0	68.4	0.	0.	68.4	71.1	0.	0.	71.1
7	55.5	0.	0.	55.5	60.5	0.	0.	60.5	77.5	0.	0.	77.5
8	64.0	0.	0.	64.0	68.2	0.	0.	68.2	98.6	0.	0.	98.6
9	61.8	0.	0.	61.8	66.1	0.	0.	66.1	124.4	0.	0.	124.4
10	61.9	0.	0.	61.9	66.2	0.	0.	66.2	128.8	0.	0.	128.8
11	59.6	0.	0.	59.6	64.0	0.	0.	64.0	148.5	0.	0.	148.5
12	61.7	0.	0.	61.7	66.2	0.	0.	66.2	162.1	0.	0.	162.1
13	61.4	0.	0.	61.4	66.1	0.	0.	66.1	175.3	0.	0.	175.3
14	66.4	0.	0.	66.4	71.0	0.	0.	71.0	143.8	0.	0.	143.8
15	71.7	0.	0.	71.7	76.3	0.	0.	76.3	261.7	0.23	0.	381.7
16	67.7	0.	0.	67.7	72.0	0.	0.	72.0	96.3	0.	0.	96.3
17	74.0	0.	0.	74.0	78.1	0.	0.	78.1	80.3	0.	0.	80.3

Secondary Route*

JOB 16015- 16032 DISTANCE 31.76 MILES

VEH #	DRY GO	DRY NG	DRY LF	DRY TT	WET GO	WET NG	WET LF	WET TT	SNOW GO	SNOW NG	SNOW LF	SNOW TT
1	75.8	0.	0.	75.8	81.7	0.	0.	81.7	104.2	0.	0.	104.2
2	83.0	0.	0.	83.0	87.7	0.	0.	87.7	108.9	0.	0.	108.9
3	118.6	0.	0.	118.6	124.2	0.	0.	124.2	151.4	0.	0.	151.4
4	121.0	0.	0.	121.0	126.5	0.	0.	126.5	156.0	0.	0.	156.0
5	121.1	0.	0.	121.1	126.6	0.	0.	126.6	156.1	0.	0.	156.1
6	85.1	0.	0.	85.1	90.0	0.	0.	90.0	99.1	0.	0.	99.1
7	87.3	0.	0.	87.3	92.2	0.	0.	92.2	112.5	0.	0.	112.5
8	96.4	0.	0.	96.4	100.5	0.	0.	100.5	127.2	0.	0.	127.2
9	93.3	0.	0.	93.3	97.6	0.	0.	97.6	149.9	0.	0.	149.9
10	93.6	0.	0.	93.6	97.9	0.	0.	97.9	153.9	0.	0.	153.9
11	87.6	0.	0.	87.6	93.0	0.	0.	93.0	175.9	0.	0.	175.9
12	94.5	0.	0.	94.5	99.8	0.	0.	99.8	195.1	0.	0.	195.1
13	94.8	0.	0.	94.8	101.2	0.	0.	101.2	208.9	0.	0.	208.9
14	96.7	0.	0.	96.7	102.9	0.	0.	102.9	175.1	0.	0.	175.1
15	110.2	0.	0.	110.2	118.6	0.	0.	118.6	258.9	3.93	0.	954.9
16	95.2	0.	0.	95.2	100.6	0.	0.	100.6	122.1	0.	0.	122.1
17	92.9	0.	0.	92.9	98.5	0.	0.	98.5	184.8	0.	0.	184.8

* Similar predictions made for tertiary route.

Table 7

Sample Formulated Printout of Job Time Prediction Sent General Research Corporation

for Use in Tactical Vehicle Fleet Simulation (TVFS) Model

Job		Vehicle	Distance	Job Time Predictions (minutes x 10)								
				Dry			Wet			Snow		
Node	Node	No.	miles. x 100	Primary Route	Secondary Route	Tertiary Route	Primary Route	Secondary Route	Tertiary Route	Primary Route	Secondary Route	Tertiary Route
2206	1106	1	794	126	345	139	136	356	149	149	359	161
2206	1106	2	794	149	400	159	153	409	163	175	412	184
2206	1106	3	794	250	741	282	257	792	289	286	756	317
2206	1106	4	794	256	742	288	263	795	295	299	760	330
2206	1106	5	794	256	742	288	264	799	295	299	760	330
2206	1106	6	794	159	466	173	162	470	177	160	467	175
2206	1106	7	794	151	401	158	158	483	165	178	670	185
2206	1106	8	794	199	533	220	202	533	222	236	549	256
2206	1106	9	794	185	517	190	187	517	192	296	781	299
2206	1106	10	794	185	517	190	187	517	193	302	788	386
2206	1106	11	794	148	411	167	156	439	174	368	893	380
2206	1106	12	794	161	402	178	171	472	188	477	969	1604
2206	1106	13	794	162	426	181	175	527	193	435	827	450
2206	1106	14	794	174	440	191	186	530	204	330	822	353
2206	1106	15	794	223	585	237	244	745	259	885	1570	899
2206	1106	16	794	186	394	189	195	427	198	202	418	209
2206	1106	17	794	179	382	193	189	446	202	177	362	190
2206	1036	1	989	160	217	195	174	229	202	189	241	223
2206	1036	2	989	190	258	221	196	264	228	223	401	256
2206	1036	3	989	323	471	390	332	403	390	366	498	436
2206	1036	4	989	329	473	396	338	485	404	382	511	452
2206	1036	5	989	329	473	397	338	486	405	303	511	453
2206	1036	6	989	205	290	243	209	294	299	207	293	249
2206	1036	7	989	196	295	234	203	299	831	1058	1262	1096
2206	1036	8	989	496	595	1351	499	597	1471	302	503	340
2206	1036	9	989	238	338	266	241	341	343	1206	1397	1227
2206	1036	10	989	238	338	266	241	341	336	1212	1402	1233
2206	1036	11	989	189	260	240	198	270	249	1303	1505	1320
2206	1036	12	989	204	261	248	216	289	259	1647	1849	2341
2206	1036	13	989	208	273	257	222	317	270	561	767	599
2206	1036	14	989	218	283	267	233	319	201	1255	1444	1298
2206	1036	15	989	283	380	329	308	433	357	1899	2061	1921
2206	1036	16	989	232	279	253	243	295	858	257	304	292
2206	1036	17	989	226	269	245	239	300	313	227	265	251

NOTE: Index to all jobs also sent to General Research Corporation.

GRC in BCD code on magnetic tape for use in the TVFS simulations. Only the finally assessed one-way times (item e above) were sent.

TVFS-AMM Interface

42. TVFS is a flexible fleet operation and management model which generates fleet performance data as a function of fleet composition and disposition, mission demands, and performance of fleet elements. TVFS acts as dispatcher and bookkeeper. Demands for transport are accepted and met on a first-come, first-serve plus priority basis, according to the availability of suitable vehicles at the dispatch point. Individual vehicles are dispatched, returned, unloaded, subjected to scheduled and unscheduled maintenance, and then returned to a ready status available for the next job, in an essentially continuous cycle.

43. As used in past studies, TVFS computes the time from vehicle dispatch to return (travel time plus loading time at the depot) by means of simple algorithms involving straight-line distances from unit to depot (modified by a small number of multipliers for route indirectness) and associated, broadly assigned average speeds reflecting vehicle type, route, and conditions (plus, of course, a depot loading time). Teaming TVFS and AMM in the HIMO Study involved replacing the more simply computed vehicle travel times with the job times predicted using AMM, which more realistically reflect inherent vehicle capabilities and route, terrain, and prevailing weather conditions.

44. GRC made the necessary programming modifications to TVFS to use the precomputed one-way job travel times supplied by WES (doubled for the round trip) in place of previous internal computations, to add depot times, and when vehicles of more than one type were dispatched on one job, to assign as the job travel time the maximum for any of the vehicles in the mix. This was the only interaction within vehicle groups and among vehicle types that was played.

45. Final use of TVFS involved, in addition to the job travel times, inputs from TRADOC for supply consumption rates at the unit level appropriate to the combat posture and intensity and for the basis for

assignment of vehicles to each unit. It also required reliability and maintenance data, which were supplied by TACOM.

Combat Unit Area Analysis

46. Subareas within the study area that were designated during the scenario map play as being occupied at one time or another by a combat unit were aggregated, and areal performance predictions under wet conditions were made for each vehicle in the subtotal "combat unit area" for each study area. This analysis was made to examine individual vehicle capabilities for delivering ammunition and fuel directly to combat vehicles and batteries, in place, rather than requiring the vehicles to return to the roadside for resupply or the transfer of the supplies to other means of conveyance (including men) from the roadside to the batteries.

47. Combat unit area boundaries were input to the computer using a manually operated digitizing line-follower and overlaid on the stored areal terrain unit maps. Areal terrain units within each subtotal area were identified, and the proportion of the subtotal area occupied by each terrain unit was determined. Performance predictions were made using AMM and processed to produce off-road speed profiles (Appendix A, paragraph 33).

M60A2 Speed Maps

48. The complete areal terrain unit maps and data are so complex as to be virtually incomprehensible without a program. To indicate the mobility aspects of the terrain in readily understandable terms, the speed of the M60A2 tank in areal terrain in the normal year, wet condition, was mapped at 1:50,000 as an overlay for the basic topographic maps. When overlaid, the maps show the omnidirectional off-road speed of the M60A2 in direct relation to features identified on the topographic maps and indicate the relative difficulty of the associated terrain on a single-number scale.

49. The M60A2 speed maps were made by printing out the basic map

cell array, i.e. substituting cell-by-bell the predicted omnidirectional speed in the terrain unit for the terrain unit identification. Cell size was chosen at the outset of the study so that the array, printed in proper format on a standard high-speed computer printer (Appendix B, paragraph 3), constitutes a map at 1:25,000 scale. Figure 7 shows a small portion of the M60A2 speed map for the Mid-East study area at 1:50,000 (made by a 2:1 reduction in a commercial copying machine). Clear acetate overlays were supplied to TRADOC as a separate product under this study.

Mobility Performance Statistics

50. A number of statistical representations of the extensive vehicle performance data developed in the course of the HIMO Study were prepared. These are presented and discussed in Appendix D, and those considered most meaningful are summarized and briefed in Part IV of the report. The particular statistics assembled are described in the next six paragraphs.

Link statistics

51. The data characterizing the composite route network links, when considered as-is, constitute a large, essentially unbiased sample of the roads and trails in the two study areas. The same links considered as all off-road traverses are a large, demonstrably unbiased sample of the total off-road terrain. The link terrain unit and distance data were used to develop a number of area-wide, nonmission-oriented statistics about the on- and off-road performance of vehicles.

52. For each study area and each condition (wet, dry, and sand in the Mid-East area, or snow in the West Germany area), average speed, percentage of distance that was NOGO, and travel times spent in crossing linear features were computed for individual vehicles on all links as-is and as off-road traverses. To provide some perspective on these numbers, the same measures were developed as averages for all vehicles in the study, each considered once. (This, of course, was not a properly stratified sample for fleet discussion but serves as a useful

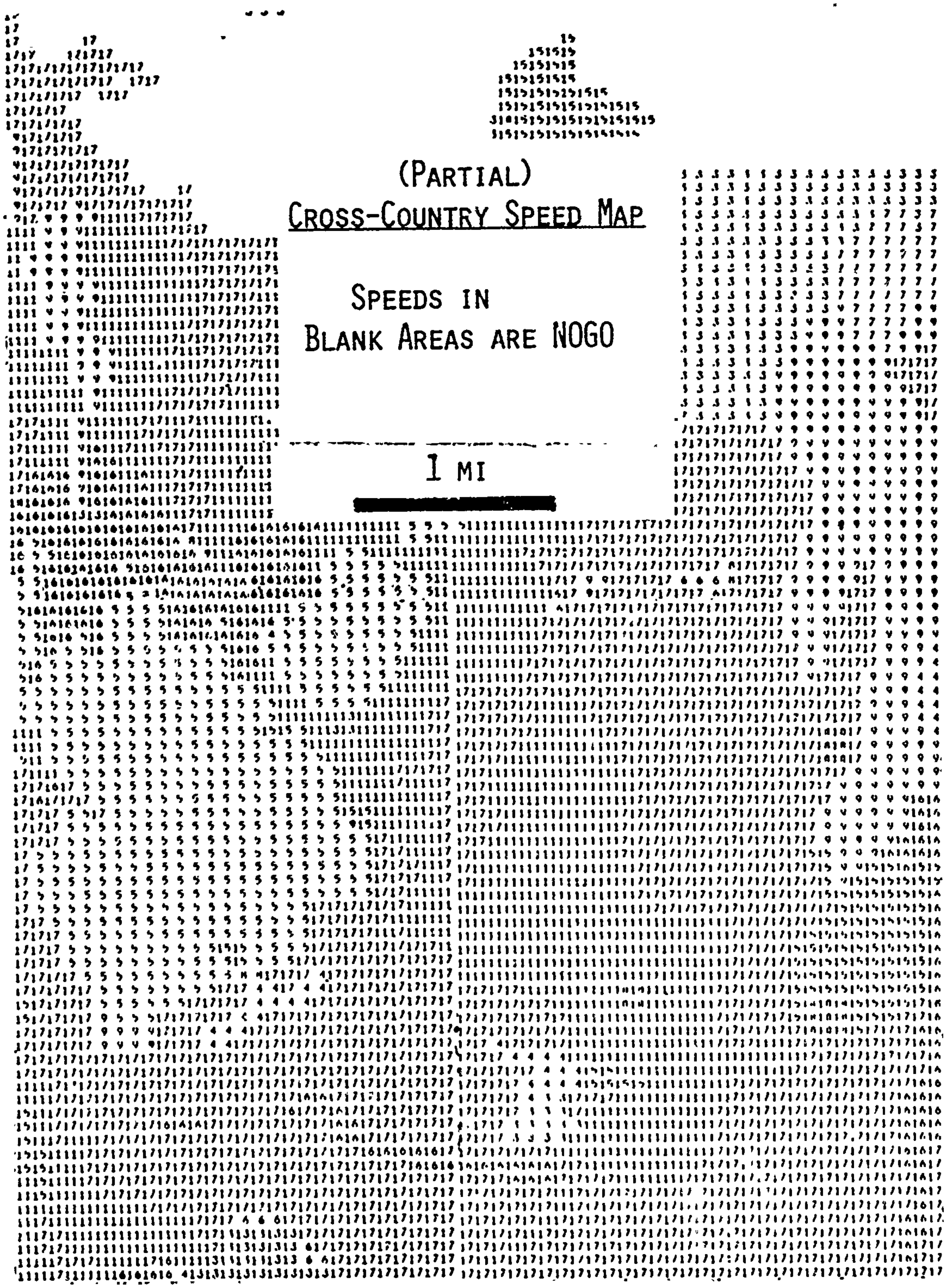

Figure 7. Partial cross-country speed map, M60A2 tank

reference for present purposes.)

53. Using the as-is network as an area-wide sample, performance of individual vehicles in areal off-road terrain and on roads, trails, and off-road traverses for each area was expressed for each condition in terms of off-road and on-road speed profiles. These speed profiles indicate the average speed that the specific vehicle can sustain in a given area (or set of roads) and condition as a function of the percentage of total area (or road distance) under consideration that it is able to avoid, assuming that it avoids those areas (or roads) that offer the greatest difficulties to the vehicle. Two indices of vehicle mobility in the areal off-road terrain, deriving from the off-road speed profile for a given situation, were computed: V_{90}, used in the 1972 DA WHEELS Study,[9] and I_{cc}, an index presently under study by TACOM (Appendix D, paragraphs 33-35). Speed profiles were developed for the area covered by one topographic map sheet in each full study area. The single map sheet selected for each area, covering 13 percent of the total Mid-East study area and 16 percent of the West Germany area, is considered to be reasonably representative of the area as a whole but is not, of course, completely analogous (Appendix D, paragraphs 26-28).

54. The relative occurrence of reasons for NOGO and speed-limiting factors associated with the on- and off-road speed profiles were also developed. These diagnostics not only indicate the controlling vehicle-terrain interactions for specific vehicles but also show the nature of the terrain in the terms of vehicle problems more generally.

Job statistics

55. Job time and speed performance data for each vehicle, operating in the two study areas over each of three routes under three conditions, developed for use in TVFS, were consolidated in terms of average job speeds, average percentage of jobs encountering areal terrain or on-road NOGO situations, and average percentage of jobs involving significant problems with linear feature crossings. The job statistics, although not yet fully mission-oriented, do consider repetitive use of links among all job routes and hence better reflect

the demands on mobility inherent in the missions generated in the scenario map play than do the similar values based solely upon analysis of the link performance data.

Percent-off-road speed profiles

56. The link performance data were used to develop a statistical representation of the average speed performance of each study vehicle in the several area-condition situations as a function of percentage of off-road travel required. The percent-off-road speed profiles, unlike the off-road and on-road speed profiles, do not assume any avoidance of particularly difficult areal terrain or roads and trails but do include the effects of linear-feature-crossing-time assessments.

PART IV: ASSESSMENT OF MOBILITY OF STUDY VEHICLES

Results of Nonmission-Oriented Statistical Examinations

57. Values for the several statistical representations of the study data briefly described in the paragraphs just preceding are presented and discussed in detail in Appendix D. Important conclusions from each of the several examinations are summarized here in relation to a number of key issues, and a concluding assessment is made from them.

General speed levels

58. The average speeds of all study vehicles, each running with rated payload in off-road terrain and over all roads and trails in an area, are modest in comparison with automotive standards based on operations on good roads. Table 8 summarizes some area-wide average speeds for the M813, 5-ton truck, 6x6, under various conditions. The M813 speeds and the trends they show are representative of the situation for all vehicles. Distance-weighted average speeds drop drastically as more and more bad roads or bad terrain situations are included in the sample. Speeds drop still further when the necessity to cross streams, canals, embankments, etc., embedded in the off-road terrain is also considered. Speed values in a given area and condition must be judged in relation to norms of the orders shown. A vehicle capable of maintaining an average speed of 4 mph will still accomplish a 10-mile mission in 50 min less time than one that can maintain only 3 mph. When the going is tough, a 1-mph improvement is not insignificant.

59. For all conditions in both areas, speed performance on roads and trails of the best study vehicle in a given condition ranges from 1.5 to 10.2 times that of the worst in the same condition; whereas, in off-road operations the range of relative best-to-worst is from 1.8 to 8.7 (Table D3). When the proportion of on-road to off-road operation is roughly adjusted to reflect mission requirements (in the job statistics), the range of relative best-to-worst performance in a given condition is 6.0 to 19.4 in the Mid-East study area, and 1.6 to 12.1 in the

Table 8

Influence of Missions, Area, and Conditions on Average Speed

Performance of M813, 5-Ton Truck, Cargo, 6x6

	Average Speed, mph					
	Mid-East			West Germany		
	Dry	Wet	Sand	Dry	Wet	Snow
Missions all on roads and trails without linear feature crossings						
Best 1% of all roads only	55	55	50	55	50	15
All roads plus 10% best trails	20	16	16	28	26	12
Missions all off roads without linear feature crossings						
Best 1% area terrain	22	21	16	30	22	20
Best 50% of areal terrain	16	15	4	20	14	10
Missions with on-and off-road NOGO's and linear feature crossings						
All on roads and trails	12	9	6	20	14	10
50-50	6	4	2	4	3	3
All off roads	3	2	1	2	2	2

West Germany study area (Table D28). Clearly, the low absolute speeds being dealt with should not be allowed to obscure real and potentially important performance differences.

Individual vehicle speed levels

60. When the performances of individual vehicles are examined, the first thing found is that the performance characteristics of the GOER vehicles (M520E1, M559, and M553) are qualitatively different from the characteristics of all of the other study vehicles, including the M60A2. In general, average speeds of the GOER's in areal off-road terrain and on roads and trails are low, but the vehicles continue on into more of the most severe terrain situations before becoming immobilized (Figures D1-D20). In the complete on- or off-road situation, including linear feature crossings, the performance of the GOER vehicles is less than or approximately the same as that of the other vehicles in the better operating situations, with a tendency to become the same or clearly superior in the more difficult situations, largely as a result of encountering fewer NOGO's (Appendix D, paragraph 13). For example, in the Mid-East study area when converted to an all-sand-dune terrain and in the West Germany study area under snow conditions, both severe (Appendix D, paragraphs 11 and 55) special conditions, the GOER vehicles, among all of the standard Army wheeled vehicles examined in the study, best matched the tracked vehicles (M60A2 and M548E1) in terms of percentage of areal terrain or on-road distance that is negotiable (Figures D5, D6, D11, D12, D15, D16, D19, and D20). Because of this and despite clearly lower speeds in GO terrain, when the total overall on- and off-road picture is put together, the performance of the GOER vehicles is good (but not outstanding), except in the Mid-East study area treated as an all-sand-dune terrain, where it is exceptional (Figures D21-D26).

61. Because of their anomalous overall speed performance characteristics, the GOER vehicles might better be considered as special-purpose vehicles rather than as elements of the general Army combat support fleet. Blanket inclusion of the GOER vehicles in the high-mobility fleet study accordingly distorts evaluation of the potential of

high-mobility vehicles in the full range of combat support roles that such vehicles must fulfill.

62. The overall performance of the TDW901 demonstrates the possibilities for 1970 technology to provide a vehicle characterized by the same order of resistance to immobilization as the GOER's, combined with speed performance in GO situations that is comparable to that of the other vehicles in the general support fleet (Appendix D, paragraphs 14, 59, 62, 70).

63. Individual vehicle speed performance not including NOGO's was examined by comparing vehicles in the same payload category, i.e. 1-1/4-ton M561 versus M715E1, 5-ton M656 versus M813, and 8-ton TDW901 versus M520E1. These examinations show that in the dry and wet areal terrain conditions, the first vehicle in each pairing is 3 percent slower to 94 percent faster than the second, with an overall mean of about 50 percent (Table D10), and 13 percent slower to 55 percent faster on the better roads and trails, with a mean of about 20 percent (Table D13). In context of the limited mission weighting of route severity given by the specific job routes defined in the scenario play, the general order of improvement is about 20 percent (Table D35).

64. Among the slower reference vehicles in each of the above comparisons (M715E1, M813, and M520E1), the 5-ton M813 is most competitive with its higher mobility comparison vehicle (M656) in the wet and dry conditions in each area, but is generally less competitive in the somewhat more severe special conditions (sand in the Mid East study area, snow in the West Germany study area).

65. The speed superiority of the M561, M656, and TDW901 over the M715E1, M813, and M520E1 demonstrated in areal terrain and on roads and trails is consistent throughout the logistic, tactical attack and tactical delay jobs developed in the scenario play (Table D35). That is, the vehicles that perform best in the more numerous logistic jobs also perform best in the other two roles, and usually by about the same margins.

NOGO's in areal terrain and on roads and trails

66. To use vehicle speed as the basic measure of vehicle perform-

ance, vehicle immobilizations for whatever reason must be converted to delay times. The somewhat arbitrary rules by which this was done are presented and discussed in paragraphs 36-40. These rules led to additions to travel times which accounted for some 40 percent of the overall areal terrain travel times and approximately 20 percent of average job travel times in the West Germany area.

67. Apart from the time assessed, relative frequency of NOGO situations, expressed in terms of percentage of areal terrain or road distance, is a critical factor in vehicle assessment. Serious vehicle immobilizations require the assistance of recovery crews or commitment of engineer resources to maintain movement and thus often involve support by Army elements other than those operating the vehicles.

68. Under dry and wet conditions in the Mid-East study area, areally distributed obstacles such as boulders, ditches, and walls cause most NOGO's in the areal terrain (Tables D14 and D15). Some minor soil slipperiness problems develop during the wet season (Table D6). The wheeled M520E1 and TDW901 have little difficulty (Table D6). Over the job routes, the smaller vehicles (M151A2, M561, and M715E1) have the most problems, but even these vehicles generally encounter NOGO situations on less than 3 percent of the job routes (Table D36).

69. In the West Germany study area in the wet and dry conditions, NOGO's in the areal terrain are caused by extensive forested areas that are more or less impenetrable according to vehicle geometry and traction capabilities (Tables D17 and D18). In the wet season, reduced soil strengths and soil slipperiness increase problems in forest negotiation and additionally cause immobilizations on slopes and in some bottom lands (Tables D7, D17, and D18). In the study area as a whole (Table D7), the GOER vehicles (M520E1, M559, and M553) have fewest NOGO's in dry conditions but encounter considerably more in wet conditions (Appendix D, paragraphs 19-20). The TDW901 experiences consistently few NOGO's in either condition. The remaining vehicles are all about the same with regard to NOGO frequency. The same trends are seen in relative NOGO's over the job routes (Table D36), but (except for the M818-M127A1C tractor-trailer) none of the vehicles encounter areal terrain or

trail NOGO's on more than 2 percent of the job routes.

70. The special conditions, sand in the Mid-East study area and snow in the West Germany study area, generally present problems which differ from those characteristic of dry and wet conditions in the areas. The Mid-East area all-sand-dune terrain presents relatively little difficulty to the two tracked vehicles (M60A2 and M548E1), but the wheeled vehicles encounter significant traction and flotation problems, both off-road (Tables D6 and D16) and on the associated sand trails (Tables D6 and D22). The GOER vehicles (M520E1, M559, and M553) and the TDW901 perform relatively well in the areal terrain (15 and 19 percent NOGO's, respectively); the M561, poorly (40 percent NOGO); and the remaining vehicles, barely at all (Table D6). The frequency of job routes involving NOGO's follow the same trend, from 1-2 percent of routes presenting NOGO situations to the GOER's and TDW901 to 6-7 percent for most of the standard vehicle fleet (Table D36). Fitting suitable tires to those wheeled vehicles with poor or worse performance would improve their performance substantially in this terrain.

71. NOGO's in the areal terrain of the West Germany study area with snow cover are generally comparable to those in the wet condition except for the M818-M127A1C tractor-trailer which, because of the heavily loaded, unpowered trailer axles, has drastic traction problems both on and off road (Tables D7, D19 and D25). Job route NOGO's reflect the same relations but again at a significantly reduced scale across the board (Table D39).

Linear feature crossings

72. Time assessed for crossing rivers, streams, canals, embankments, and similar linear terrain features during off-road travel averages 0.5 to 1 min per mile in the Mid-East study area and 4 to 20 min per mile in the West Germany study area, depending on the vehicle and conditions. On the off-road links of the Mid-East area, these times generally constitute only 1-4 percent of the total travel time, but in the West Germany area, they are of the order of 40 percent of the total.

73. In the Mid-East area, excessive delays which are involved only during the wet season when the dry drainage features are active affect

eight of the vehicles because of fording problems and egress problems on slippery banks (Table D8). These vehicles encounter the same difficulties in a significant number of the job routes (Table D42).

74. Excessive linear crossing delays occur for all of the vehicles in the West Germany study area for swimming and nonswimming vehicles alike (Table D9). The tracked M548E1, a swimmer, and the M60A2, a nonswimmer, have almost the same problems; whereas, all the wheeled vehicles encounter linear-feature-crossing problems twice as often. Over the job routes, however, the tracked vehicles encounter excessive time delays in approximately the same percentage of job routes as most of the wheeled vehicles, and the swimming vehicles appear to have no significant advantage (Table D43).

Vehicle performance as a function of percentage of travel off-road

75. In Appendix D, percent-off-road speed profiles are shown for all of the study vehicles in each study area and condition (paragraphs 67-72, Figures D21-D26). The average speeds shown in these profiles reflect the combined influences of all roads, trails, areal terrain, and linear features, including NOGO situations. The percent-off-road speed profiles demonstrate, principally, that ground crawling is a slow business when roads are unavailable or denied. This is a fact of life, as was indicated at the outset of this discussion (paragraph 58). The presentation in Appendix D, however, overshadows the range of the differences that exist among the vehicles and potential importance of these differences.

76. Figures 8-13 provide a different perspective. These figures were developed from the same data as the figures in Appendix D by considering the associated mission travel time rather than vehicle speed as a function of percentage of the route that is off-road. The average of one-way MSR and secondary route distances for all types of jobs (Table 4) was taken in each study area as a reasonable one-way mission distance. Resulting one-way travel times in hours are shown.

77. Clearly, the small speed differences among the vehicles, when forced into operations where speeds are low, become of great signifi-

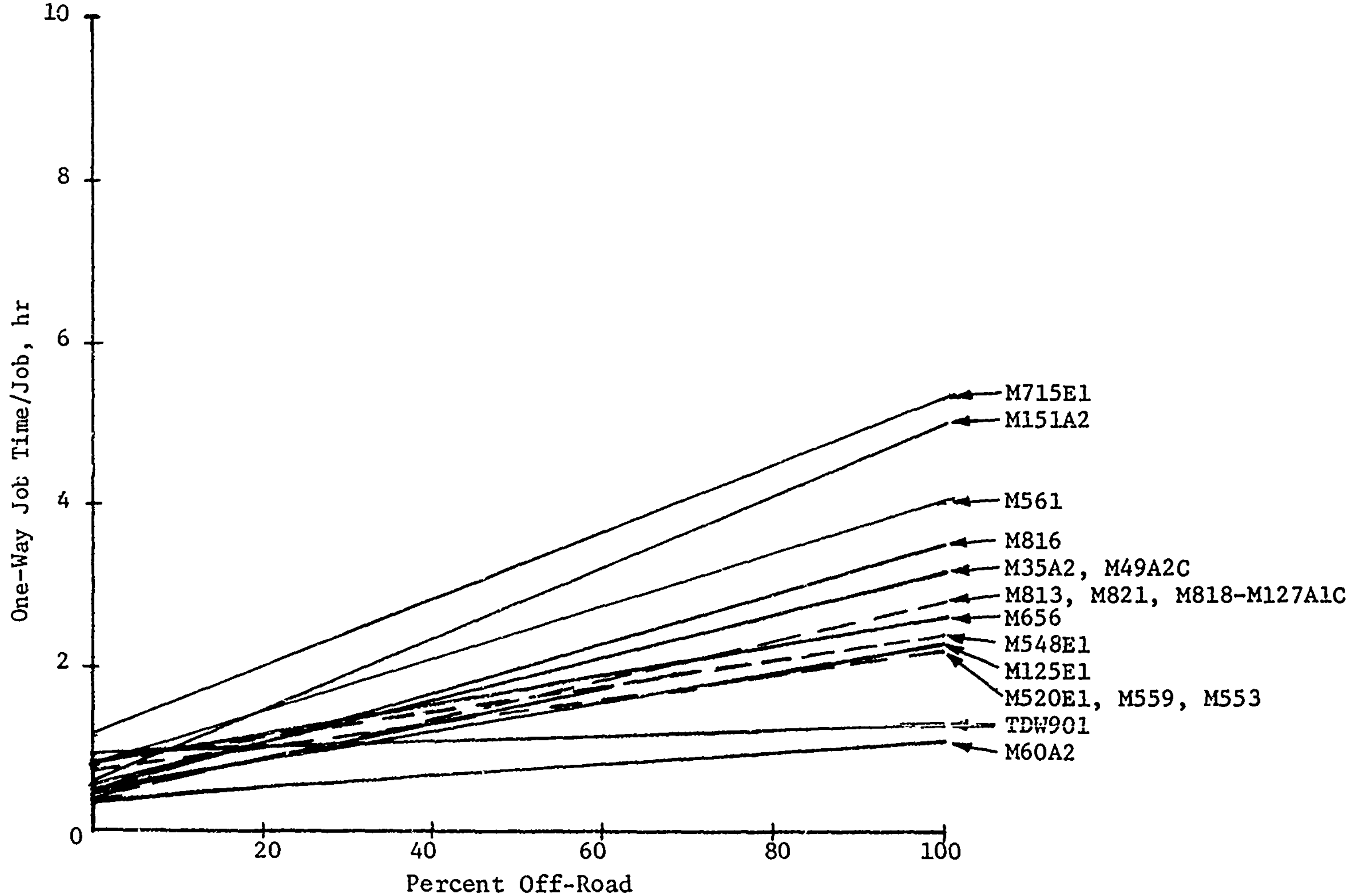

Figure 8. Mean job travel time as a function of percent off-road, Mid-East, dry

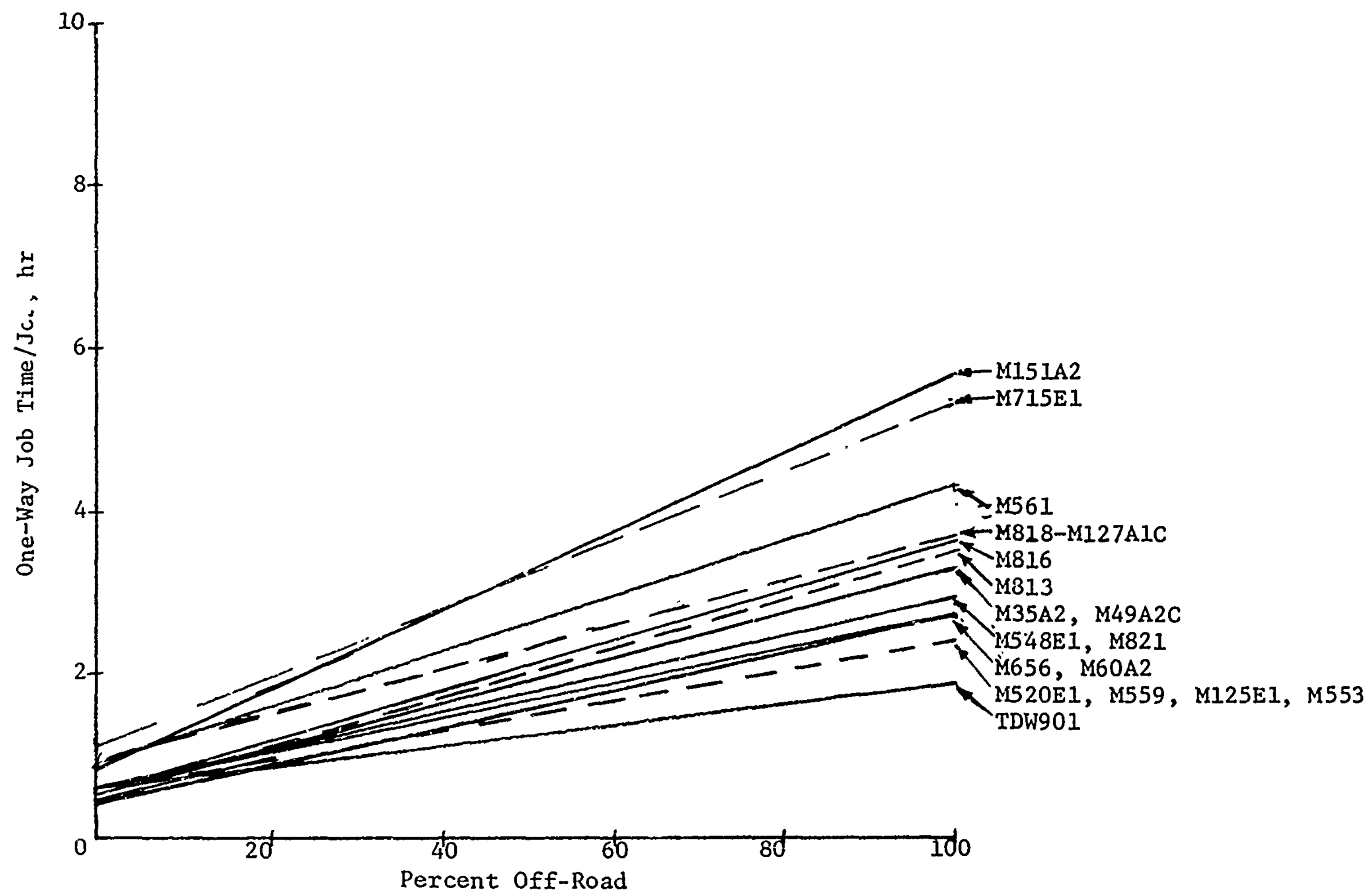

Figure 9. Mean job travel time as a function of percent off-road, Mid-East, wet

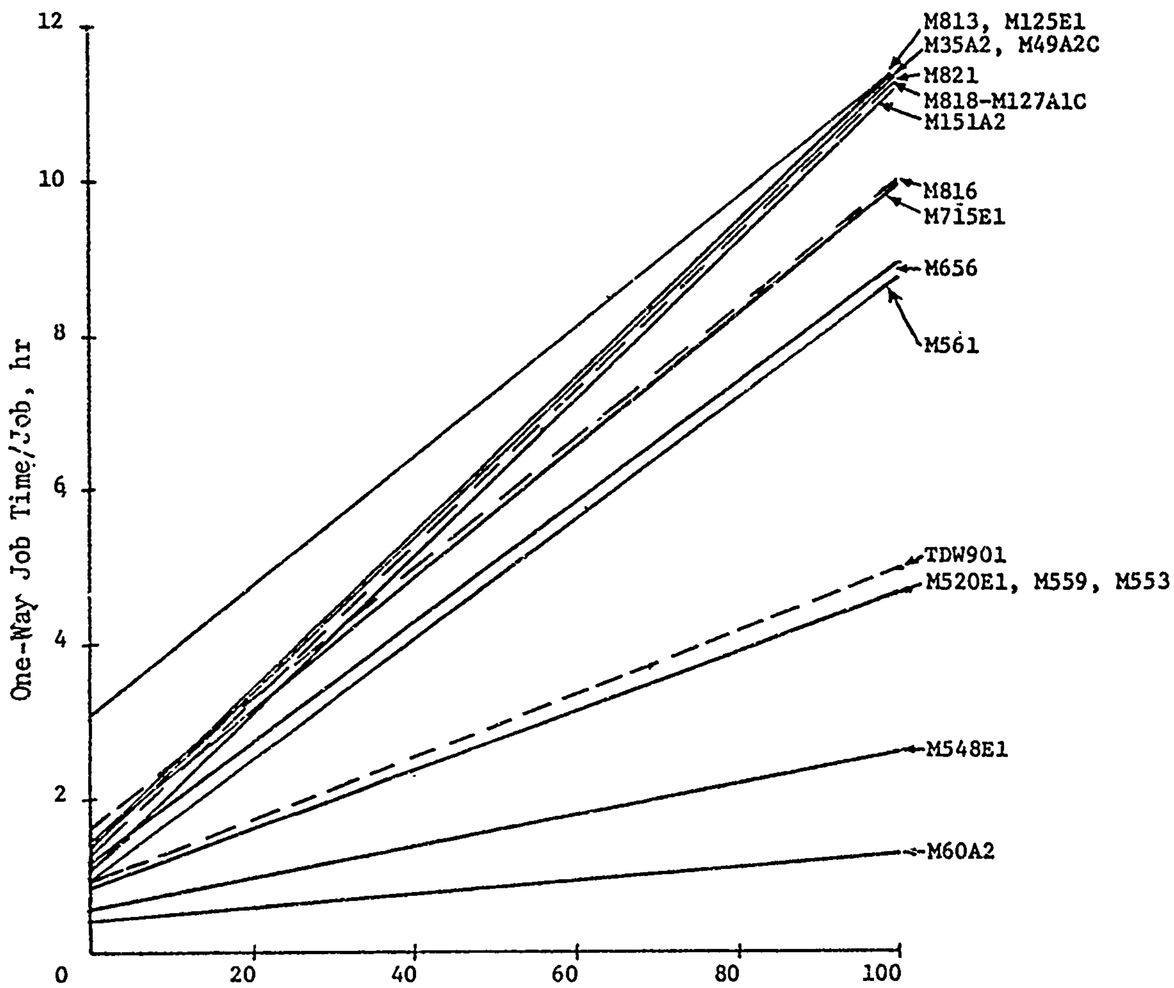

Figure 10. Mean job travel time as a function of percent off-road, Mid-East, sand

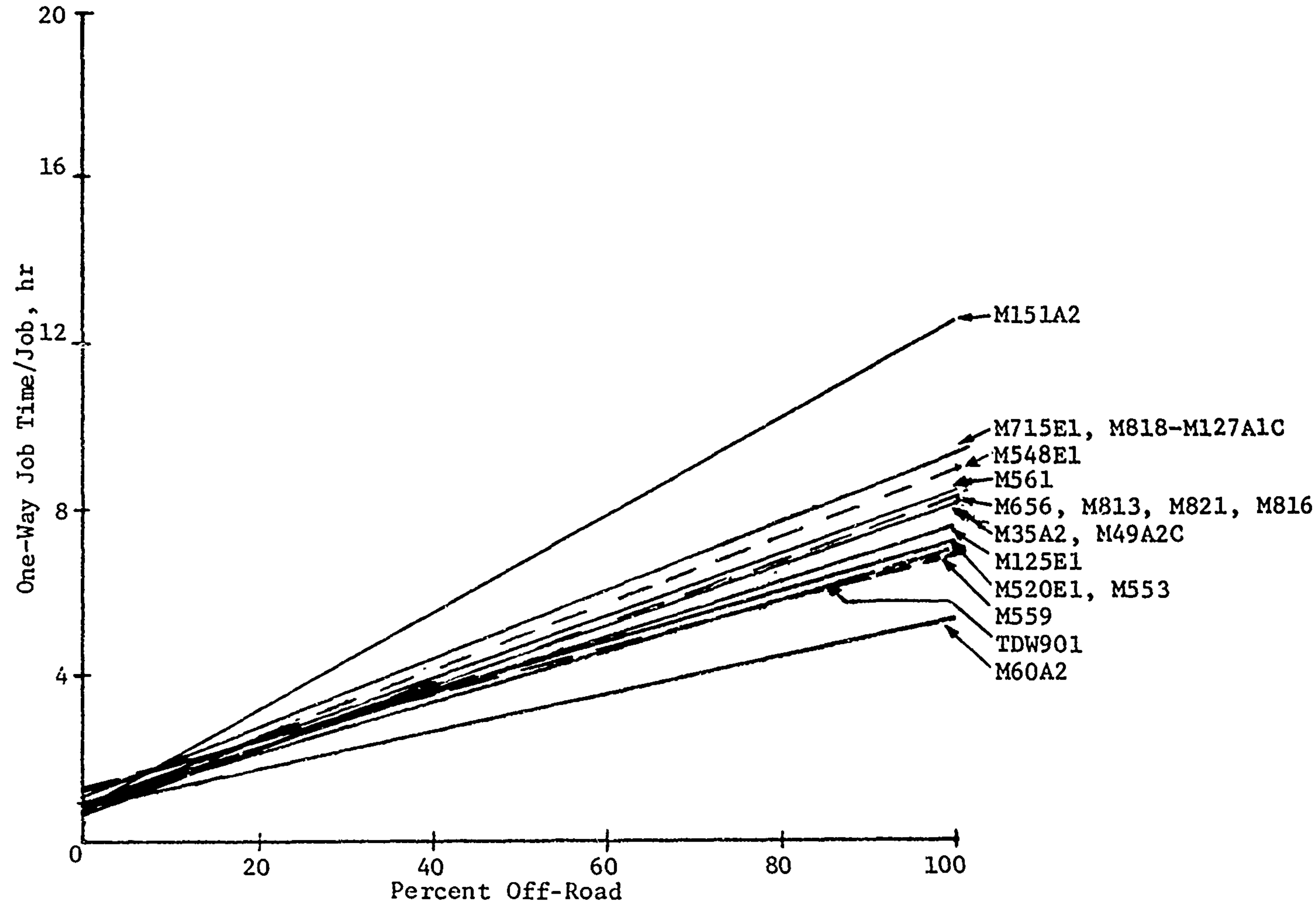

Figure 11. Mean job travel time as a function of percent off-road, West Germany, dry

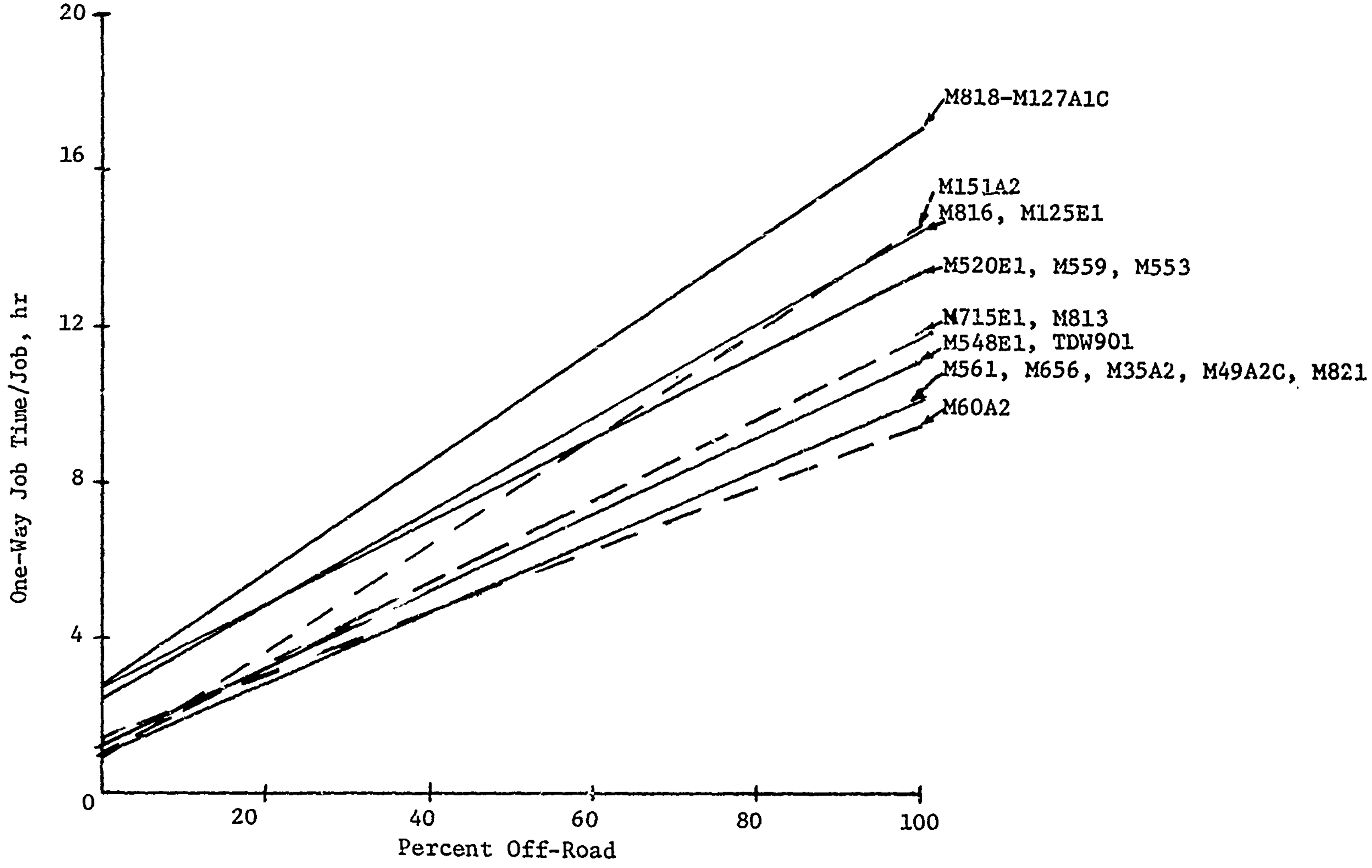

Figure 12. Mean job travel time as a function of percent off-road, West Germany, wet

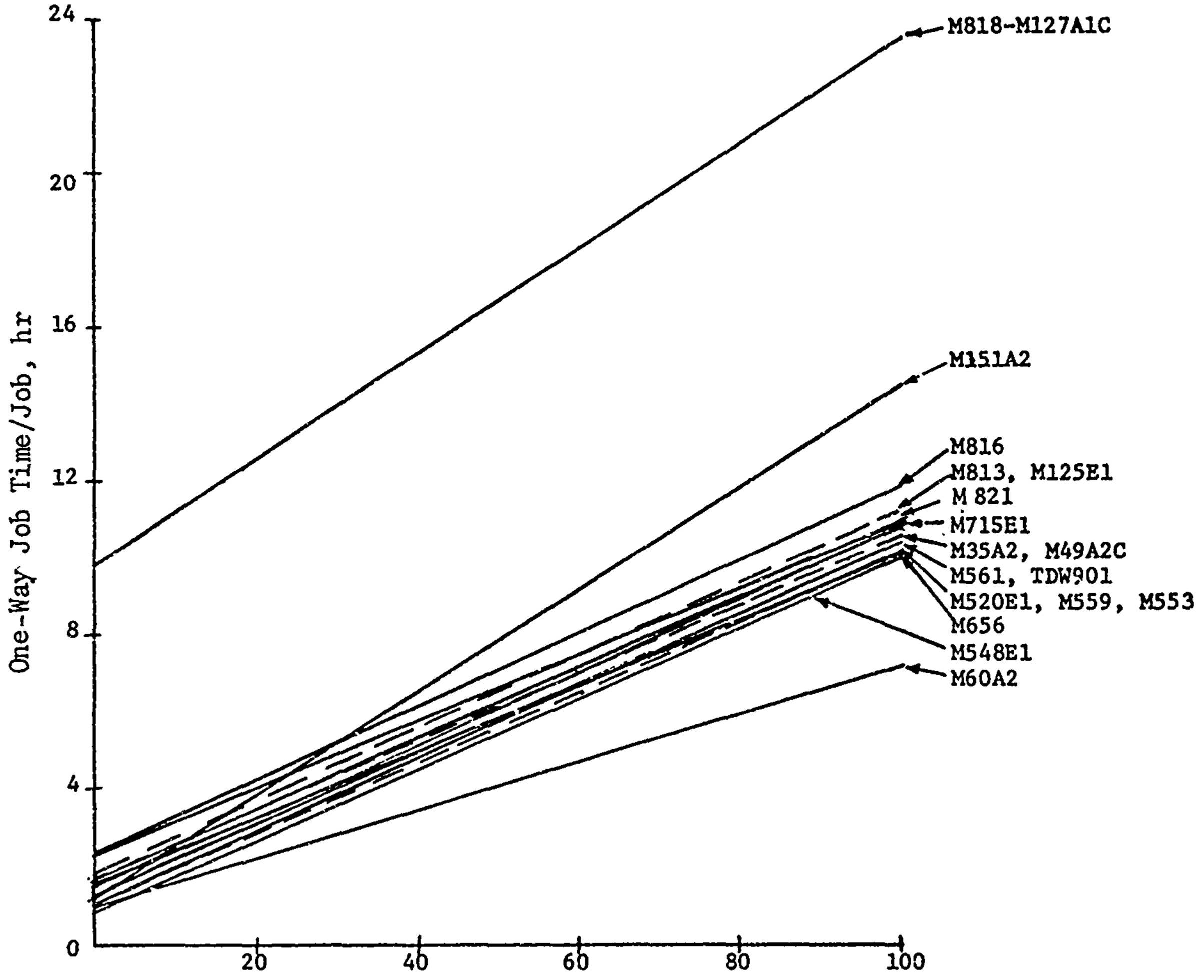

Figure 13. Mean job travel time as a function of percent off-road
West Germany, snow

cance in terms of the hours of difference in travel time. Consider the times in the West Germany study area under dry conditions (Figure 11). The corresponding percent-off-road speed profile (Figure D24) suggests that differences for all but two of the study vehicles are insignificant, especially when a large proportion of the mission is off-road. In terms of travel time, however, the fastest vehicle (TDW901) in this area and condition among the remaining 15 will accomplish a typical 18.8-mile job requiring 50 percent off-road travel in 3.9 hr. The slowest vehicle (M818-M127A1C) of the 15 will take 6 hr to do the same job, more than an hour longer.

78. Table 9 summarizes mean one-way travel times for each vehicle on the average job in each study area under conditions requiring 50 percent of the travel distance to be accomplished off road. Table 10 shows associated reductions in expected one-way travel time when higher-mobility vehicles are used in place of lower-mobility vehicles. While the reductions vary with area, condition, and the specific vehicle comparison, in 10 of 18 comparisons the average overall reduction in travel time for a complete two-way mission is over 1 hr per job.

Mobility levels

79. The requirement for 50 percent of job travel distance to be off road is severe in comparison to the mission routes developed in scenario play. The composite as-is route networks developed in scenario play are comprised almost entirely of roads and trails. Only 18.1 percent of the Mid-East and 0.1 percent of the West Germany study areas route network are off road. Comparison of the performance statistics over the job routes with corresponding values for operations over the entire route network, both as-is and as an off-road traverse, clearly shows that the basic MSR and secondary job routes involved even fewer off-road traverses. The partial MSR interdiction played added an average of 8 percent off road in the Mid-East study area (largely replacing trails) and only 4 percent in the West Germany study area. As a result, the off-road mobility of the study vehicles was not severely taxed. In terms of the 1972 DA WHEELS Study[1] definitions of levels of mobility (footnote of paragraph 3a), the worst routes in the study would

Table 9

Mean One-Way Job Travel Times for Routes Involving 50 Percent of Off-Road Distance

	One Way Travel Time, hr					
	Mid-East Average Job: 8.0 miles			West Germany Average Job: 18.8 miles		
Vehicle	Dry	Wet	Sand	Dry	Wet	Snow
M561	2.42	2.83	4.94	4.70	5.73	5.80
M656	1.59	1.61	5.04	4.50	5.72	5.51
M520E1	1.53	1.52	2.81	4.19	8.09	5.73
M559	1.53	1.55	2.83	4.07	8.09	5.75
M553	1.46	1.55	2.83	4.20	8.09	5.75
M548E1	1.44	1.74	1.55	4.91	6.22	5.43
M151A2	2.89	3.31	6.26	6.66	7.70	7.85
M715E1	3.21	3.24	5.70	5.16	6.16	6.62
M35A2	1.86	1.95	6.41	4.47	5.71	6.38
M49A2C	1.86	1.95	6.41	4.47	5.71	6.38
M813	1.63	2.03	6.40	4.49	6.46	6.49
M821	1.65	1.72	6.58	4.53	5.78	6.61
M816	2.02	2.14	5.85	4.53	8.47	7.02
M125E1	1.44	1.49	6.40	4.21	8.47	6.46
M818/M127A1C*	1.70	2.56	7.31	5.02	9.97	16.70
TDW901	0.91	1.27	2.94	3.95	6.08	5.83
M60A2	0.75	1.67	0.87	3.14	5.38	4.10

* All values suspect because some NOGO's probably were not called.

Table 10

Job Travel Time Reduction for Jobs Routes 50 Percent Off-Road

Vehicles		Travel Time Reduction					
		Mid-East			West Germany		
		Dry	Wet	Sand	Dry	Wet	Sand
1-1/4-ton trucks							
M561 in place of M715E1	minutes*	47	25	46	28	26	49
	percent	25	13	13	9	7	12
5-ton trucks							
M656 in place of M813	minutes*	2	25	82	-1	44	59
	percent	2	21	21	0	11	15
8-ton trucks							
TDW901 in place of M520E1	minutes*	37	15	-8	14	121	-6
	percent	41	16	-5	6	25	-2

* Reduction in one-way travel time for mean job distance (Mid-East 8.0 miles, West Germany 18.8 miles).

presumably require little more than tactical support mobility.

Vehicle performance in combat unit areas

80. In terms of vehicle performance, characteristics of that areal terrain within the two study areas designated during scenario play as being occupied at one stage or another by combat units are essentially the same as for the two areas as a whole (Appendix D, paragraphs 73-75). As a result, the area-wide areal terrain NOGO figures (such as those in Tables D6 and D7, off road) are a suitable basis for judging the relative capabilities of the study vehicles for moving about within the relatively small combat unit areas for any purpose.

Comparative Off-Road Ride Severity

81. A special analysis was made of the ride performance of seven of the study vehicles during off-road travel in the Mid-East study area under dry conditions, because this situation was the most severe from the viewpoint of ride of any examined in the study. This special analysis used previously made speed and GO-NOGO predictions for the average speed of each vehicle in the subset of areal terrain that did not cause any immobilizations, the associated time-average of absorbed power (watts) at the driver's station, and the resulting average of energy absorbed by the driver per mile of travel (watt-hours per mile). Results are shown in Table 11.

82. AMM computes several speeds as limited by various mechanical and driver constraints and selects the least of these as the predicted speed in a given terrain situation. (Appendix A, paragraph 6). One of these is the speed at which driver absorbed power just reaches 6 watts. When some other constraint such as power imposes a lower limit, driver absorbed power is at some lower level. As a result, the average absorbed powers for all vehicles are less than 6 watts. Table 11 shows that the average absorbed power does not vary greatly among the vehicles examined except in the case of the M60A2.

83. When the average speed associated with the average absorbed power is considered, however, the relative ride severity of the several vehicles--in this terrain and condition--becomes more apparent. The

Table 11

Comparative Off-Road Ride Severity at Driver's Station

Mid-East Area, Dry Condition

Vehicle	Average GO Speed mph	Average Absorbed Power Level watts	Average Absorbed Energy watt-hours per mile
M656, 5-ton, 8x8	9.8	3.9	0.40
M520E1, 8-ton, 4x4	4.8	3.7	0.77
M548E1, 5-ton, tracked	8.8	4.2	0.48
M151A2, 1/4-ton, 4x4	9.2	4.6	0.50
M813, 5-ton, 6x6	6.4	3.8	0.59
TDW901, 8-ton, 8x8	12.0	3.2	0.27
M60A2, tank	7.9	2.0	0.25

average energy absorbed by the driver in traveling 1 mile indicates that the driver of an M60A2 or a TDW901 will accomplish a given travel mission, having absorbed about one-half the total energy that drivers of an M813 would absorb and one-third that absorbed by drivers of the GOER vehicles. There are no data to prove it, but it seems reasonable to assume that driver fatigue in accomplishing a given travel mission is closely related to the total vibration energy his body absorbs during the mission.

Vehicle Comparisons in Relation to WHEELS Study Mobility-Level Definitions

84. The mobility performance of a vehicle is a complex function of the vehicle characteristics, the terrain in which it is operating, and the tasks it is required to do. This is amply illustrated by the several grossly aggregated statistics discussed and is even more apparent in the more detailed statistical examinations presented in Appendix D. Expressing mobility performance in a reduced set of comprehensible numbers to aid in making decisions at the DA level is a formidable task. The tactical mobility classifications defined in the 1972 DA WHEELS Study[1] offer a possibility to do so, nonetheless.

85. The WHEELS Study defined three levels of tactical mobility These are quoted in Table 12, along with the identification of two additional mobility levels (high-high and on-road mobility) which complete the possible range. The original WHEELS definitions are unquantified but suggest the possibility for quantification (for a given geographical area and condition) in terms of three numbers, the last two of which corresponding statistical data are available from the HIMO predictions:

- a. Percentage of off-road travel expected of the vehicle.
- b. The severity of expected off-road travel (in terms of the percentage of the off-road terrain that should be negotiable).
- c. The portion of the road and trail network in the area on which the vehicle is expected to function (in terms of the quality of the roads as reflected in sustainable speeds).

Table 12

Preliminary Quantification of WHEELS Study Definitions of Tactical Mobility[1]

Mobility Level	Operating Distance		Severity of Operation	
	Off-Road Percent	On-Road Percent	Off-Road* Percent of Terrain Challenged	On-Road Percent of Trails Included
High-high mobility**				
All off-road operation	100	0	100	-
Tactical high mobility				
The highest level of mobility designating the requirement for extensive cross-country maneuverability characteristic of operations in the ground-gaining and fire-support environment.	50	50	90	100
Tactical standard mobility				
The second highest level of mobility designating the requirement for occasional cross-country movement.	15	85	80	100
Tactical support mobility				
A level of mobility designating the requirement for infrequent off-road operations over selected terrain with the preponderance of movement on primary and secondary roads.	5	95	50	50
On-road mobility**				
All on superhighways, primary and secondary roads, and the best tertiary roads and trails.	0	100	-	10

* In terms of percentage of best off-road terrain to be challenged (off-road speed profile).
** Not a WHEELS Study definition.

Assignment of the above values for a given vehicle and for each definition of mobility level permits calculation of an average, area-wide rating speed which the vehicle can maintain in the stated weather conditions while performing missions requiring each level of mobility.

86. Table 12 proposes for each WHEELS mobility level and the two added reference levels a reasonable, associated set of values for a percentage of off-road operation and severity levels for the off-road terrain and a percentage of trails within an area network that should be readily negotiable when that percentage is made up of the least difficult trails in the area. These values were used in the calculation procedure given in Appendix E, based on the on- and off-road speed profiles discussed in paragraphs 75-77, to assign an overall average rating speed for each vehicle operating in both areas and under all conditions according to the stated requirements for all five levels of mobility.

87. Tables 13-18 show the resulting rating speeds based on data in Appendix D for all study vehicles in the Mid-East and West Germany study areas, each under three conditions. Of the many observations that can be made from this tabulation, perhaps the most important is that, relative to the best vehicle shown for a given mobility level, the rating speeds for a given vehicle tend to drop off precipitously at some point as the mobility level increases. All do, that is, except rating speeds for the GOER vehicles (M520E1, M559, and M553). The GOER figures tend rather to show a more steady decline, which results in improved relative standings as the mobility level increases.

88. A second observation is that the rating speeds for the M60A2 in both areas, all conditions and levels, are generally equal to or somewhat higher than the average rating speeds for the other vehicles in the study. This makes the M60A2 a reasonable vehicle to which to reference the others, regardless of area, condition, or mobility level, even though operationally it may only be completely appropriate as a reference for the high- and high-high mobility levels.

89. Table 19 presents in a single matrix the rating speeds for each vehicle (given in Table 13-18) in relation to the speed of the

Table 13

Vehicle Performance at Specified Levels of Tactical Mobility Performance in Mid-East, Dry Condition

	Average Speed, mph, for Specified Tactical Mobility Levels				
Vehicle	On-Road	Support*	Standard*	High*	High-High
M561	24.1	18.5	12.5	2.3	0.6
M656	25.7	19.5	15.2	4.4	0.7
M520E1	15.8	12.3	9.5	7.4	2.9
M559	15.6	12.1	9.3	7.2	2.9
M553	15.6	12.1	9.3	7.3	2.9
M548E1	22.4	17.6	14.1	7.0	0.8
M151A2	27.4	20.4	11.5	1.5	0.5
M715E1	18.3	14.6	11.4	1.8	0.5
M35A2	24.6	20.1	16.4	3.2	0.7
M49A2C	24.6	20.1	16.4	3.2	0.7
M813	29.4	21.5	14.8	4.8	0.8
M821	26.0	20.8	14.5	6.2	0.8
M816	25.8	19.9	14.0	4.2	0.7
M121E1	24.7	19.4	13.8	10.8	0.9
M818-M127A1C	18.7	14.7	11.5	9.4**	1.7**
TDW901	22.6	19.8	16.3	14.3	2.9
M60A2	24.9	22.2	17.6	13.9	8.6

* WHEELS Study[1] definitions, quantified per Table 12.

** Values suspect - some NOGO's probably were not called (Appendix A, paragraph 14-17).

Table 14

Vehicle Performance at Specified Levels of Tactical Mobility Performance in Mid-East, Wet Condition

Vehicle	Average Speed, mph, for Specified Tactical Mobility Levels				
	On-Road	Support*	Standard*	High*	High-High
M561	23.4	17.9	12.2	2.3	0.6
M656	24.0	18.3	14.3	4.2	0.7
M520E1	13.5	10.8	8.5	6.6	2.8
M559	13.3	10.7	8.4	6.6	2.8
M553	13.3	10.7	8.4	6.6	2.8
M548E1	21.1	16.6	7.9	3.8	0.7
M151A2	26.9	19.5	11.8	1.3	0.5
M715E1	17.9	14.4	11.3	1.8	0.5
M35A2	23.4	19.2	15.5	3.1	0.7
M49A2C	23.4	19.2	15.5	3.1	0.7
M813	24.8	19.2	13.6	6.6	0.8
M821	21.1	17.5	12.8	5.7	0.8
M816	19.4	16.2	12.0	3.3	0.7
M121E1	19.1	16.3	12.2	8.7	0.9
M818--M127A1C	13.7	11.7	1.7	1.4**	1.1**
TDW901	20.9	18.1	14.3	11.2	2.5
M60A2	21.4	19.0	13.8	10.6	1.0

* WHEELS Study[1] definitions, quantified per Table 1.

** Values suspect - some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table 15

Vehicle Performance at Specified Levels of Tactical Mobility Performance in Mid-East, Sand Condition

Vehicle	Average Speed, mph, for Specified Tactical Mobility Levels				
	On-Road	Support*	Standard*	High*	High-High
M561	20.4	15.4	0.5	0.4	0.2
M656	17.7	14.4	0.5	0.4	0.2
M520E1	11.0	9.0	0.9	0.7	0.5
M559	10.4	8.5	0.9	0.7	0.5
M553	10.3	8.5	0.9	0.7	0.5
M548E1	18.2	14.8	11.2	5.0	0.8
M151A2	19.1	4.7	0.4	0.3	0.2
M715E1	16.6	12.4	0.4	0.3	0.2
M35A2	18.4	0.5	0.3	0.1	0.1
M49A2C	18.4	0.5	0.3	0.1	0.1
M813	17.7	4.9	0.4	0.3	0.2
M821	2.4	0.3	0.2	0.1	0.1
M816	13.5	6.0	0.4	0.3	0.2
M121E1	2.8	0.3	0.2	0.1	0.1
M818-M127A1C	2.6	0.3	0.2	0.1	0.1
TDW901	14.3	12.6	0.9	0.7	0.4
M60A2	18.8	16.5	12.4	10.1	6.9

* WHEELS Study[1] definitions, quantified per Table 12.

Table 16

Vehicle Performance at Specified Levels of Tactical Mobility Performance in West Germany, Dry Condition

Vehicle	Average Speed, mph, for Specified Tactical Mobility Levels On-Road	Support*	Standard*	High*	High-High
M561	28.2	24.1	18.2	13.3	0.7
M656	26.6	23.3	18.9	13.6	0.8
M520E1	18.3	16.1	12.5	8.0	2.6
M559	17.8	15.6	12.2	7.7	2.8
M553	17.7	15.6	12.2	7.8	2.8
M548E1	25.0	22.2	18.2	13.3	0.7
M151A2	30.5	26.4	20.8	2.0	0.6
M715E1	25.0	21.4	16.8	11.6	0.7
M35A2	28.7	25.5	20.5	14.6	0.8
M49A2C	28.7	25.5	20.5	14.6	0.8
M813	28.0	24.3	18.7	12.5	1.2
M821	24.7	22.0	17.3	11.8	1.1
M816	24.7	21.8	17.2	11.6	1.1
M121E1	24.0	21.3	16.7	11.5	1.4
M818-M127A1C	19.1	16.8	13.6	9.1**	1.1**
TDW901	21.8	20.0	16.8	12.4	1.2
M60A2	23.2	21.4	18.0	13.1	2.4

* WHEELS Study[1] definitions, quantified per Table 12.

** Values suspect - some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table 17

Vehicle Performance at Specified Levels of Tactical Mobility Performance in West Germany, Wet Condition

Vehicle	Average Speed, mph, For Specified Tactical Mobility Levels				
	On-Road	Support*	Standard*	High*	High-High
M561	26.7	22.6	16.9	11.8	0.7
M656	25.4	21.8	17.2	11.5	0.8
M520E1	17.5	14.9	9.3	6.4	2.0
M559	17.0	14.6	9.2	6.3	2.0
M553	16.9	14.7	9.2	6.3	1.9
M548E1	23.9	20.8	16.6	4.3	0.6
M151A2	28.7	24.4	18.7	2.8	0.7
M715E1	24.0	20.2	16.0	10.8	0.7
M35A2	27.5	23.8	18.6	12.4	0.7
M49A2C	27.5	23.8	18.6	12.4	0.7
M813	26.5	22.4	16.9	10.6	1.1
M821	23.3	20.0	15.1	9.5	1.1
M816	23.1	19.6	11.6	8.6	1.1
M121E1	22.6	19.6	11.8	8.9	1.1
M818-M127A1C	18.0	15.6	8.2	4.0**	0.8**
TDW901	21.0	18.8	15.2	10.3	1.0
M60A2	22.2	20.0	16.0	10.5	1.3

* WHEELS Study[1] definitions, quantified per Table 12.
** Values suspect - Some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table 18

Vehicle Performance at Specified Levels of Tactical Mobility Performance in West Germany, Snow Condition

Vehicle	Average Speed, mph, For Specified Tactical Mobility Levels				
	On-Road	Support*	Standard*	High*	High-High
M561	21.6	19.0	14.9	11.3	0.7
M656	20.4	18.2	15.0	11.1	0.8
M520E1	13.7	12.3	10.2	6.8	2.2
M559	13.1	11.9	9.9	6.6	2.1
M553	13.1	12.0	9.8	6.6	2.1
M548E1	23.4	20.7	16.9	12.7	0.7
M151A2	22.3	19.7	16.0	2.8	0.7
M715E1	16.8	15.2	12.7	9.3	0.7
M35A2	13.9	13.1	11.5	9.0	0.7
M49A2C	13.9	13.1	11.5	9.0	0.7
M813	11.6	11.0	9.7	7.4	1.1
M821	10.1	9.6	8.6	6.6	1.1
M816	9.4	9.0	8.1	6.2	1.0
M121E1	11.6	10.9	9.6	7.2	1.2
M818-M127A1C	0.8	0.6	0.3	0.2	0
TDW901	17.6	16.0	13.4	10.0	1.0
M60A2	23.2	20.9	16.9	12.3	2.3

* WHEELS Study[1] definitions, quantified per Table 12.

M60A2 tank. Relative speeds are shown in terms of tens of percent; i.e., the number 8 for a given vehicle, area, condition, and mobility level indicates that the corresponding rating speed for the vehicle, when rounded to the nearest 10 percent, is 80 percent of the rating speed of the M60A2 in the same area, condition, and level of mobility.

90. The performance profiles summarized in Table 19 matrix reveals essentially six major groupings of study vehicles:

Special excursion truck	TDW901	(1970+)
High-mobility trucks/carriers (except the GOER's)	M561, M656, M548E1	(1960-1970)
Standard trucks	M35A2, M49A2C M813, M821, M816	(1955-1960)
GOER's	M520E1, M559, M553	
1/4-ton utility truck	M151A2	
Semitrailer rig	M818-M127A1C	

The performance of the M715E1, 1-1/4-ton truck, is similar to that of the standard trucks in the West Germany Study area and conditions, but has generally lesser capabilities than these trucks in the Mid-East situations. The M125E1, 10-ton truck, on the other hand, performs as a standard truck in the West Germany situations but outperforms all but the 8-ton TDW901 in the Mid-East wet and dry conditions.

91. The most striking feature of the matrix in Table 19 is the distinctly different performance profile of the GOER vehicles. Their performance is relatively poor at levels of mobility in which the other high-mobility carriers and the standard vehicles perform well but is regularily superior at the higher mobility levels. At these levels, only the TDW901 is competitive. Its good performance, however, consistently extends to the lower levels as well.

92. The low rating speeds of the familiar M151A2 in high- and high-high mobility roles also require comment. These speeds reflect small but significant increases in NOGO difficulties relative to larger vehicles which are otherwise compa.able. The real off-setting advantages of the small vehicle--in terms of more opportunities and capabilities for detailed on-the-ground route optimization and for relatively easy recovery--are not reflected in the basic performance

Table 19

Study Vehicle Rating Speeds Relative to the M60A2 at Five Levels of Tactical Mobility

Vehicle*	Mid-East Dry 1	2	3	4	5	Mid-East Wet 1	2	3	4	5	Mid-East Sand 1	2	3	4	5
M561	10**	8	7	2	1	11	9	9	2	6	11	9	0	0	0
M656	10	9	9	3	1	11	10	10	4	7	9	9	0	0	0
M520E1	6	6	5	5	3	6	6	6	6	28	6	5	1	1	1
M559	6	5	5	5	3	6	6	6	6	28	6	5	1	1	1
M553	6	5	5	5	3	6	6	6	6	28	5	5	1	1	1
M548E1	10	9	8	5	1	10	10	7	3	-	10	10	10	5	1
M151A2	11	9	7	1	1	13	10	9	1	5	10	3	0	0	0
M715E1	7	7	6	1	1	8	8	8	2	5	9	8	0	0	0
M35A2	10	9	9	2	1	11	10	11	2	7	10	0	0	0	0
M49A2C	10	9	9	2	1	11	10	11	2	7	10	0	0	0	0
M813	12	10	8	3	1	12	10	10	6	8	9	3	0	0	0
M821	10	9	8	4	1	10	9	9	5	8	1	0	0	0	0
M816	10	9	8	3	1	9	9	9	3	7	7	4	0	0	0
M125E1	10	9	8	8	1	9	9	9	8	9	1	0	0	0	0
M81S-	8	7	7	7	2	6	6	1	1	1	1	0	0	0	0
M127A1C† TDA901	9	9	9	10	3	10	10	10	8	25	8	8	1	1	1

Vehicle*	West Germany Dry 1	2	3	4	5	West Germany Wet 1	2	3	4	5	West Germany Snow 1	2	3	4	5
M561	12	11	10	10	3	12	11	11	11	5	9	9	9	9	4
M656	12	12	10	10	3	12	11	11	11	6	9	9	9	9	4
M520E1	8	8	7	6	11	8	7	6	6	15	6	6	6	6	10
M559	8	7	7	6	12	8	7	6	6	15	6	6	6	5	9
M553	8	7	7	6	12	8	7	6	6	15	6	6	6	5	9
M548E1	11	10	10	10	3	11	10	10	4	5	10	10	10	10	3
M151A2	13	12	12	2	3	13	12	12	3	.5	10	9	9	2	3
M715E1	11	10	9	10	3	11	10	10	10	5	7	7	8	8	3
M35A2	12	12	11	12	7	12	11	11	11	7	6	6	7	7	3
M49A2C	12	12	11	12	7	12	11	11	11	7	6	6	7	7	3
M813	12	11	10	10	5	12	11	11	10	8	5	5	6	6	5
M821	11	10	10	9	5	10	10	9	9	8	4	5	5	5	5
M816	11	10	10	9	5	10	10	7	8	8	4	4	5	5	4
M125E1	10	10	9	9	6	10	10	7	8	8	5	5	6	6	5
M81S-	8	8	8	7	5	8	8	5	4	6	0	0	0	0	0
M127A1C† TDA901	9	9	9	10	5	10	9	10	10	8	8	8	8	8	4

* Tactical Mobility Levels

1 Off-road
2 Tactical Support
3 Tactical Standard
4 Tactical High
5 High-High

(Levels 1–5: MIEELS Study[1] Definition)

** Numbers are tens of percent (i.e. 6 = 60%, 11 = 110%).

† All values suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

predictions and, hence, are not in the rating speeds. While the resulting figures accordingly may be somewhat conservative, the basic trend towards reduced mobility in context of the total range off-road terrain is considered correct.

93. The Table 19 matrix can be transformed to a simpler matrix stating the adequacy of each vehicle in each area and condition to perform missions requiring each of the stated levels of mobility by establishing a judgment criterion in terms of a vehicle's rating speed in relation to the corresponding rating speed of the M60A2. For example, if a relative rating speed of 80 percent (= 8 in the matrix)* or more is considered adequate for combat support missions, the matrix shown in Table 20 results.

94. The Table 20 matrix may be displayed in the form of two three-dimensioned cubes, one for each study area. Figure 14 shows the build-up of the cube for the West Germany study area. The data in Table 19 are first consolidated according to groupings of vehicles of interest, producing the adequacy matrices shown in Figure 14a. Adequacy in a given condition at a given level of tactical mobility is indicated by a filled rectangle. These are turned through an angle into the paper and given a nominal depth, so that adequacy is next represented by a filled block (Figure 14b). The piles of blocks are then moved together horizontally to form a solid figure. This last setup is illustrated in Figure 14c.

95. Figure 15 and 16, built-up as described, then show graphically for the two study areas the adequacy relative to the assumed adequacy criterion of each of the six groups of vehicles** to fulfill missions requiring the five levels of mobility previously defined as a function of the conditions. These two figures dramatize the truly different character of the GOER vehicles. Whereas all of the other vehicles are adequate for missions at a number of levels <u>up to</u> some maximum, the GOER's are matched essentially to only one very high level.

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* Greater than 75 percent due to the rounding process.

** Actually an especially wet condition during a light rain causing soil slipperiness (paragraph 14).

Table 20

Tactical Mobility Levels for Which Study Vehicles are Adequate*

	Tactical Mobility Levels**																													
	Mid-East															West Germany														
	Dry					Wet					Sand					Dry					Wet					Snow				
Vehicle	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
M561, 1-1/4-Ton GAMA GOAT, 6x6	X	X				X	X	X			X	X				X	X	X	X		X	X	X	X		X	X	X	X	
M656, 5-Ton Truck, Cargo, 8x8	X	X	X			X	X	X			X	X				X	X	X	X		X	X	X	X		X	X	X	X	
M520E1, GOER, 8-Ton Truck, Cargo, 4x4										X						X	X			X	X				X					X
M559, GOER, 2500-Gal Truck, Tanker 4x4										X						X				X	X				X					X
M553, GOER, 10-Ton Truck, Wrecker, 4x4										X						X				X	X				X					X
M548E1, 5-Ton Carrier, Cargo Tracked	X	X	X			X	X				X	X	X			X	X	X	X		X	X	X			X	X	X	X	
M151A2, 1/4-Ton Truck, Utility, 4x5	X	X				X	X	X			X					X	X	X			X	X	X			X	X	X		
M715E1, 1-1/4-Ton Truck, Cargo, 4x4						X	X	X			X	X				X	X	X	X		X	X	X	X				X	X	
M35A2, 2-1/2-Ton Truck, Cargo, 6x6	X	X	X			X	X	X			X					X	X	X	X		X	X	X	X						
M49A2C, 2-1/2-Ton Truck, FS, 6x6	X	X	X			X	X	X			X					X	X	X	X		X	X	X	X						
M813, 5-Ton Truck, Cargo, 6x6	X	X	X			X	X	X		X	X					X	X	X	X		X	X	X	X	X					
M821, 5-Ton Bridge Transport 6x6	X	X	X			X	X	X		X						X	X	X	X		X	X	X	X	X					
M816, 5-Ton Truck, Wrecker, 6x6	X	X	X			X	X	X								X	X	X	X		X	X		X	X					
M125E1, 10-Ton Truck, Cargo, 6x6	X	X	X	X		X	X	X	X	X						X	X	X	X		X	X		X	X					
M818, 5-Ton Truck, Tractor, 6x6 M127A1C, 12-Ton Semitrailer	X															X	X	X			X	X								
TDW901, Twister Dragon Wagon 901 8-Ton, Cargo, 8x8	X	X	X	X		X	X	X	X	X	X	X				X	X	X	X		X	X	X	X	X	X	X	X	X	

* Adequate: X = Rating speed $\geq$ 75% of M60A2 rating speed at same mobility level.
** Quantified mobility levels per Table 12.

1 On-Road
2 Support
3 Standard
4 High
5 High-High

} WHEELS Study[1] Definition

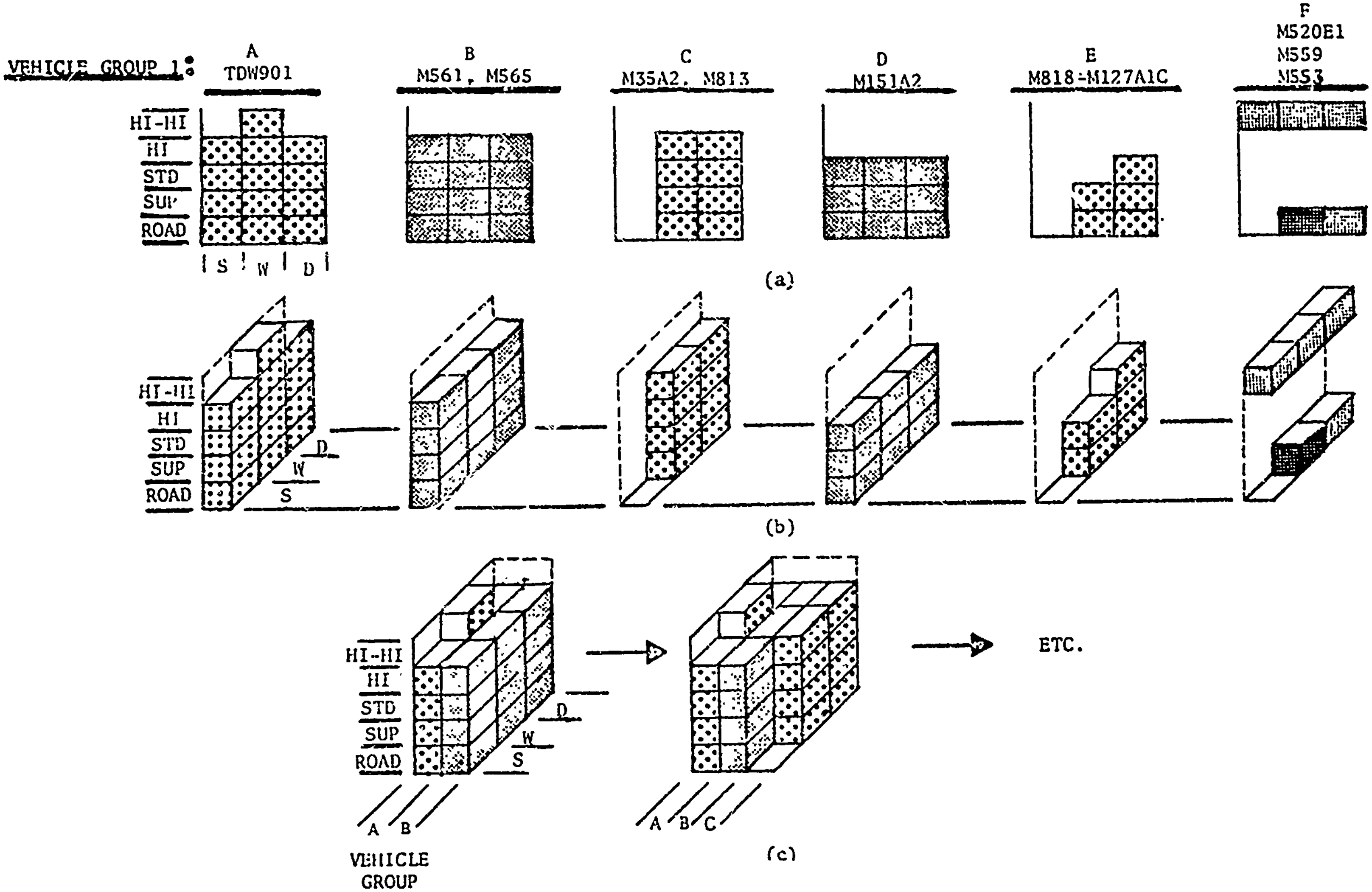

Figure 14. Buildup of three-dimensional cube representation of adequacy matrix (West Germany)

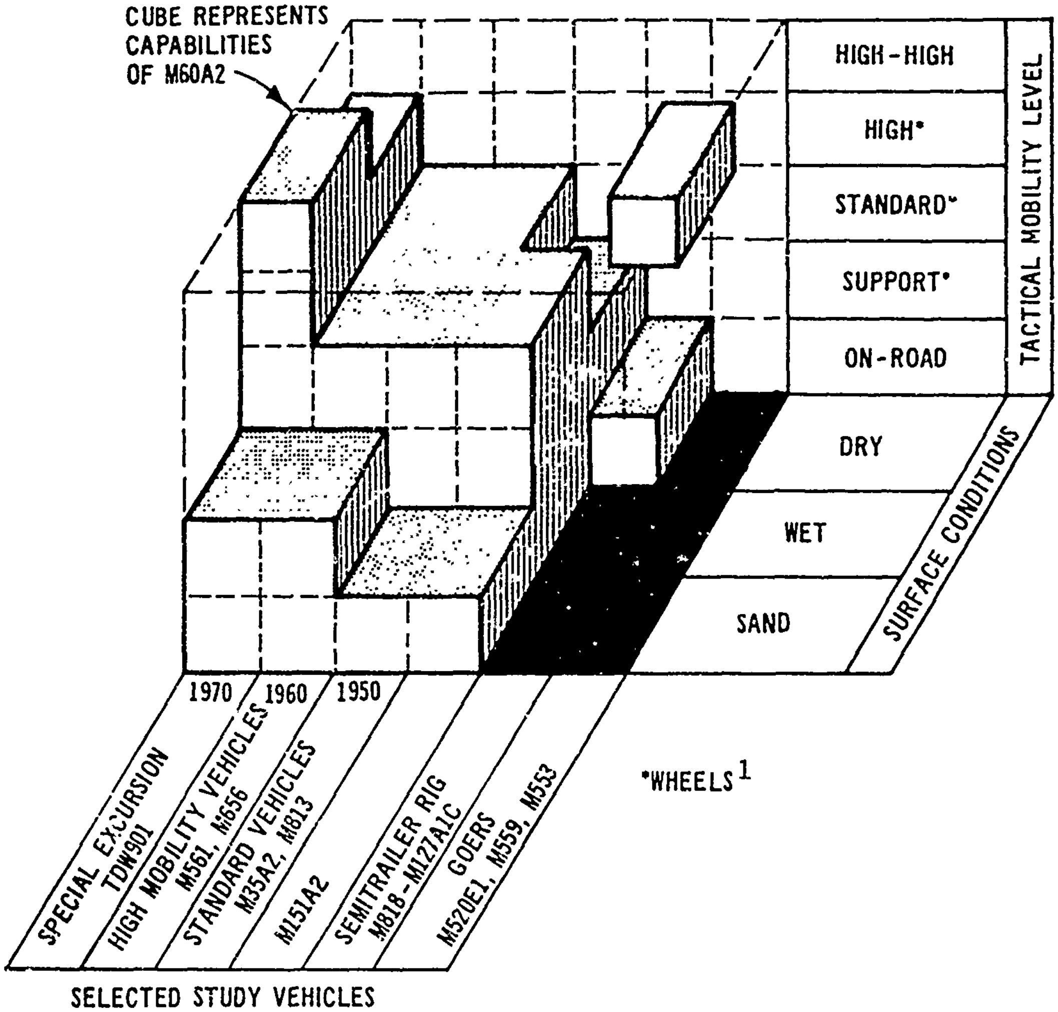

Figure 15. Tactical mobility levels of representative study vehicles (Mid-East)

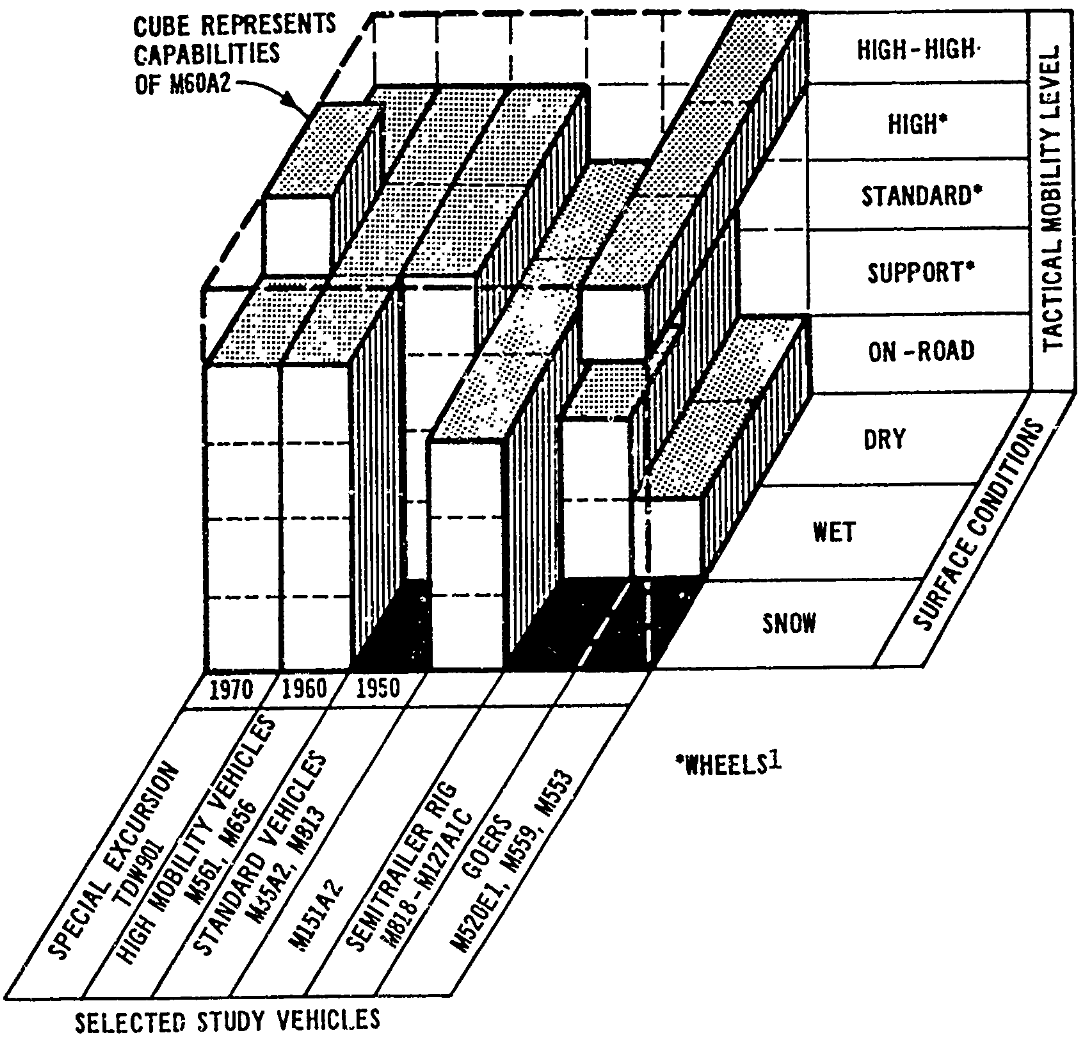

Figure 16. Tactical mobility levels of representative study vehicles (West Germany)

96. Figures 15 and 16 also show that, from the viewpoint of the full range of more usual conditions (dry to wet* in each area), the two groups of vehicles termed standard and high-mobility vehicles are both adequate for jobs requiring the same levels of mobility. Examination of the actual rating speeds shows that the high-mobility vehicles generally perform appreciably better, but the arbitrary rule assumed to determine adequacy says that the difference is not critical.

97. Comparison of the cube diagrams shown in Figures 15 and 16 leads to the conclusion that, based on the assumed criterion for adequacy, current vehicles are more suitable for operations in the West Germany study area than in the Mid-East study area. This reflects the fact that the Mid-East area is by and large relatively the more favorable for tracked vehicles (such as the M60A2 reference vehicle) in relation to wheeled vehicles.

98. It is important to note at this point that changing the reference vehicle or the acceptable level of relative performance will change the evaluation. For example, in relation to the support of a new tank which was 30 percent faster across the board, the same relative speed adequacy criterion would make all of the wheeled vehicles in the study inadequate under the special conditions (sand or snow).

99. Finally, the cube diagrams also show that progress has been made over the period 1950-1970, largely in improving mobility capabilities in special (but not unusual) operating conditions such as sand or snow. Such special conditions are frequently the basis for subjective mobility evaluations and for the concern by field personnel over mobility problems. The operational importance of such special conditions cannot be assessed from the present statistical analysis. Should they be judged important, the performance of the TDW901 demonstrates that 1970 technology can meet the challenge.

* The standard vehicles are represented by the M35A2 and M813.

PART V:. SUMMARY ASSESSMENT, CONCLUSIONS, AND RECOMMENDATIONS

Mobility of the Study Vehicles

100. The performance statistics, variously examined, provide bases for evaluating the two fleets and the individual study vehicles against the demands of terrain and missions and among themselves.

Terrain demands

101. For the climatic conditions dry and wet,* total off-road operation in the West Germany study area is more difficult than in the Mid-East study area (Tables D4 and D5). Although NOGO difficulties in the areal expanse of terrain are generally more extensive in the Mid-East areas (Tables D6 and D7), they are offset by significantly increased difficulties in crossing streams, canals, rivers, etc., in the West Germany study area (Tables D8 and D9). The overall result is that area-wide average off-road speeds for all vehicles except the M561 and the M715E1 range from 7 to 130 percent higher in the Mid-East study area than in the West Germany study area. NOGO's and speed limits in the Mid-East areal terrain are largely associated with seemingly minor obstacles and terrain roughness distributed throughout the area (Tables D14 and D15); in the West Germany areal terrain, with forests and vegetation (Tables D17 and D18).

102. When the actual soils and topography of the Mid-East study area are changed to represent an all-sand-dune terrain, the overall off-road performance of every wheeled vehicle in the study is reduced by at least 50 percent, but the speeds for the tracked M60A2 and M113A1 are essentially unaffected (Table D4). NOGO's are encountered in 40 percent or more of the area by all wheeled vehicles except the GOER's (M520E1, M559, M553) and the TDW901. These vehicles have tires whose size and deflation potential are appropriate to this type of terrain. Fitting similarly suitable tires and wheels** to any of the other vehicles could

* Actually, in this study, "wet-wet", and especially wet season during rain.

** Steering assists and special inflation/deflation kits might also be required to make up-tiring of current vehicles practical.

improve their GO/NOGO performance to approximately the levels for the GOER's and the TDW901.

103. The 10-in.-deep snow cover simulated over the West Germany study area (considered to have frozen ground beneath the snow) presents essentially the same level of impedance to off-road travel as the study wet-season condition to all vehicles except the M818-M127A1C tractor-trailer combination (Table D5). The M818-M127A1C (fully loaded) fares badly in the off-road snow condition because of the heavily loaded, unpowered axles on the trailer (Tables D7 and D19).

104. In both study areas all of the vehicles in both fleets, when operating off road and on trails, incur a large proportion of their total travel time as a result of difficulties encountered in crossing linear terrain features (streams, canals, enbankments, etc.) or in overcoming NOGO situations in areal terrain (or both). Both types of difficulty demand frequent, timely assistance from engineer or recovery elements to maintain the momentum of operational mobility required for combat support.

105. The network of MSR and secondary routes in the Mid-East study area is considerably less favorable under all conditions for all vehicles than the West Germany network. Generally, average speed over the entire network in the West Germany study area, limited for most vehicles primarily by power, is twice the speed over the Mid-East network (Tables D4 and D5) on which ride limits predominate.

Mission demands

106. The as-is network of basic MSR and secondary mission routes developed in the scenario play includes off-road traverses for 18.1 percent of the total network distance in the Mid-East study area; only 0.1 percent in the West Germany study area (Table 2). Average job speeds in the Mid-East area for all vehicles, all routes, and all conditions are substantially higher than corresponding average speeds when traveling once over each link in the entire network (Tables D29 vs D4). Comparison of average job speeds with related on-road speed profiles indicates that the total of all MSR job routes represents approximately the best 20 percent of the total network; all secondary

routes, the best 50 percent; and all tertiary (interdicted MSR) routes, the equivalent of the best 60-70 percent. Average job speeds over the MSR and secondary routes in the West Germany study area are also consistently higher than network averages, indicating that those routes not only involve no significant off-road distances but also represent effective avoidance of the more difficult roads and trails in the network. Average speeds over the combined tertiary (partially interdicted) job routes in the West Germany area are of the same order as network averages. The effects of the approximately 4 percent of off-road distance deliberately introduced to play partial MSR denial are apparently offset by the fact that (by the logic of the process used) the off-road travel tends to replace trail travel and that the better roads are repeatedly included in the total job route distance.

107. The maximum extent of off-road travel developed in the scenario play under any circumstances appears to be consistent, at most, with the level of mobility defined in the 1972 DA WHEELS Study as "tactical standard mobility: . . . . . designating the requirement for occasional cross-country movement."[1] The scenario play apparently represents current perception of ground vehicle operations required in combat support. This low expected utilization of off-road mobility capabilities, which seems to reflect an optimistic evaluation of possible road net interdiction, must for the present be considered a major finding of the study. The basic data available in the present study can be used, however, to make a first-order estimate in meaningful statistical terms of more extreme threat conditions.

Individual vehicle performance

108. A number of possible statistical bases have been developed for comparing the mobility performance of the study vehicles. Although the detailed ranking of individual vehicles varies somewhat according to the statistical measure chosen, there is broad agreement on the relative capabilities of key vehicles and especially of those vehicles that are directly comparable in terms of payload capacity.

109. Table 21 presents a final, simple basis for directly comparing the study vehicles, which is generally consistent with the trends shown

Table 21

Average Number of Mission Completions* per 10-hr Day**

	Mid-East				West Germany			
	Wet and Dry		Sand		Wet and Dry		Snow	
Vehicle	Standard	High	Support	Standard	Standard	High	Standard	High
M561	6	1	7	(0.2)†	7	5	6	4
M656	7	2	7	(0.2)	7	5	5	4
M520E1	4	3	4	(0.4)	4	3	4	2
M559	4	3	4	(0.4)	4	3	4	2
M553	4	3	4	(0.4)	4	3	4	2
M548E1	5	2	7	5	7	2	7	5
M151A2	5	(0.7)	2	(0.2)	8	1	6	1
M715E1	5	(0.7)	6	(0.2)	6	4	5	2
M35A2	7	1	(0.2)	(0.2)	8	5	4	3
M49A2C	7	1	(0.2)	(0.2)	8	5	4	3
M813	7	2	2	(0.2)	7	4	4	3
M821	6	3	(0.2)	(0.1)	6	4	3	2
M816	6	2	3	(0.2)	6	4	3	2
M125E1	6	4	(0.2)	(0.1)	6	4	4	3
M818-M127A1C††	3	2	(0.2)	(0.1)	4	2	(0.1)	(0.1)
TDW901	7	6	6	(0.4)	6	4	5	4
M60A2	7	6	8	6	7	5	7	5

* 8 hr or less travel time.

** Round-trip missions in the Mid-East, 16.0 miles each; one-way missions in West Germany, 18.8 miles each.

† Number in parentheses represents portion of mission less than one completion.

†† All Values suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

by the several statistical measures discussed earlier. The table shows the number of average missions (two-way job travel in the Mid-East study area and one-way in the West Germany study area) that can be expected to be completed in a 10-hr day (8 hr or less of travel time) by each vehicle when the mission requires tactical standard or tactical high mobility* as quantified in paragraphs 84-87.

110. Table 22 presents for each study area, in the wet and dry conditions combined, rankings of the vehicles on the basis of expected average number of mission completions indicated in Table 21, as a function of the level of mobility required by the missions. Table 23 presents rankings on the same basis for operations in the two special terrain conditions examined, sand and snow. In both tables, vehicles in the high-mobility fleet are underlined, the M60A2 and M151A2 are double underlined, and the TDW901 is enclosed by asterisks. Vehicles with the same number of expected mission completions are considered to be of the same rank, and there is no significance to the order in which the vehicles are listed within a rank group.

111. The overall picture shows that the M656 truck of the high-mobility fleet provides significantly more potential combat support (more mission completions per day) than trucks of the standard fleet in all circumstances, except on missions in the Mid-East study area requiring tactical high mobility, where their performance only equals that of comparable standard trucks. The GOER vehicles, on the other hand, generally provide potentially fewer mission completions per day than standard vehicles. Daily mission completions for the TDW901 are greater than for the GOER's in every case in which one or more missions per day can be achieved.

112. These trends are explicitly shown in Table 24, also extracted from Table 21, which directly compares expected mission completions of the 1-1/4-ton M561 and M715E1, the 5-ton M656 and M813, and the 8-ton

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* Because of the severity of the condition for wheeled vehicles, the mobility levels shown for the Mid-East sand condition are, instead, support and standard.

Table 22

Ranking of Study Vehicles According to Mission Completions
Wet and Dry Conditions
(Per Table 20)

	Tactical Standard				Tactical High			
	Mid-East		West German		Mid-East		West Germany	
Vehicle Rank	Expected Mission Completions	Vehicle	Expected Mission Completions	Vehicle	Expected Mission Completions	Vehicle	Expected Mission Completions	Vehicle
1	7	M656 M35A2 M49A2C M813 TDW901 M60A2	8	M151A2 M35A2 M49A2C	6	*TDW901* M60A2	5	M561 M656 M35A2 M49A2C M60A2
2	6	M561 M821 M816 M125E1	7	M561 M656 M548E1 M813 M60A2	4	M125E1	4	M715E1 M813 M821 M816 M125E1 *TDW901*
3	5	M548E1 M151A2 M715E1	6	M715E1 M821 M816 M125E1 *TDW901*	3	M520E1 M559 M553 M821	3	M520E1 M559 M553
4	4	M520E1 M559 M553	4	M520E1 M559 M553 M818/**	2	M656 M548E1 M813 M816 M818/**	2	M548E1 M818/**
5	3	M818/**			1	M561 M35A2 M49A2C	1	M151A2
6					<1	M151A2 M715E1		

NOTE: For quick identification, high-mobility vehicles are underlined; M151A2 and M60A2 are double underlined; and TDW901 is shown with asterisks.
** With M127A1C - values suspect because some NOGO's probably not called (Appendix A, paragraphs 14-17).

Table 23

Ranking of Study Vehicles According to Mission Completion

(Special Conditions)

	Mid-East, Sand				West Germany, Snow			
	Support		Standard		Standard		High	
Vehicle Rank	Expected Mission Completions	Vehicle	Expected Mission Completions	Vehicle	Expected Mission Completions	Vehicle	Expected Mission Completions	Vehicle
1	8	M60A2	6	M60A2	7	M60A2 M548E1	5	M548E1 M60A2
2	7	M561 M656 M548E1	5	M548E1	6	M561 M656 M151A2	4	M561 M656 *TDW901*
3	6	M715E1 *TDW901*	<1	M520E1 M559 M553 *TDW901* M561 M656 M151A2 M715E1 M35A2 M49A2C M813 M816 M821 M125E1 M818/**	5	M715E1 *TDW901*	3	M35A2 M49A2C M813 M125E1
4	4	M520E1 M559 M553			4	M520E1 M559 M553 M35A2 M49A2C M813 M125E1	2	M520E1 M559 M553 M715E1 M821 M816
5	3	M816			3	M821 M816	1	M151A2
6	2	M151A2 M813			<1	M818/**	<1	M818/**
7	<1	M35A2 M49A2 M821 M125E1 M818/**						

NOTE. For quick identification, high-mobility vehicles are underlined; M151A2 and M60A2 are double underlined; and TDW901 is shown with astericks.

** With M127A1C - all values suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table 24

Comparison of Mission Completions per 10-Hr Day* for Selected Vehicle Pairs

	Wet and Dry Conditions				Special Conditions	
	Standard		High		Support	Standard
Vehicles	Mid-East	West Germany	Mid-East	West Germany	Mid-East, Sand	West Germany, Snow
1-1/4-ton trucks						
M561	6	7	1	5	7	6
M715E1	5	6	(0.7)**	4	6	5
5-ton trucks						
M656	7	7	2	5	7	6
M813	7	6	2	4	2	4
8-ton trucks						
TDW901	7	6	6	4	6	5
M520E1	4	4	3	3	4	4
Tracked vehicles						
M60A2	7	7	6	5	8	7
M548E1	5	7	2	2	7	7

* 8 hr or less travel time.

** Number in parenthesis represents portion of mission less than one completion.

TDW901 and M520E1. Values for the two tracked vehicles in the study (M60A2 and M548E1) are included for reference.

113. The performance of the smaller, higher powered vehicles--M151A2, M561, M715E1--is generally more affected by terrain roughness and ruggedness and by weather conditions than that of the larger vehicles of nominally similar mobility. This is primarily due to vehicle size in relation to the terrain features. It is not an insuperable technical problem, however, to develop a 1/4- to 3/4-ton vehicle that will better match high-mobility fleet requirements than does the M151A2, which is presently considered a part of that fleet.

Fleet performance

114. The expected daily mission completions presented in Tables 21-24 show that, in missions requiring tactical standard mobility, the standard-mobility fleet designated in this study is exceedingly homogeneous in performance. Expected mission completions of the basic cargo carriers in wet and dry conditions range from six to seven in both study areas. Although expected completions are reduced by more stringent conditions and mission requirements, and variability across the fleet is increased, the fleet performance still tends to remain homogeneous throughout.

115. On the other hand, performance of the high-mobility fleet designated for this study (including the M151A2) is anything but homogeneous. Not only do the M561 and M656 generally lie at the opposite extremes of the ranking from the GOER vehicles, but the tracked M548E1 floats between and the M151A2 runs the gamut of the extremes. The individual vehicles thus do not constitute a wholly rational basis for a high-mobility fleet, but they do, among them, demonstrate present possibilities deliberately to design a fleet that could provide a significant increase in combat support mobility.

Conclusions and Recommendations

116. Judged by the scenario play, present perception of requirements for combat support foresees very little operation by combat support vehicles off roads and trails. This finding will require

reexamination if the threat or the performance of the combat vehicles being supported change materially.

117. Maintenance of effective operational off-road and trail mobility requires considerable, timely engineer support to assist in crossing linear terrain features and potentially immobilizing areal terrain.

> Recommendation: Present quantitative methodology for evaluating vehicle operational mobility should be extended to permit similar quantitative evaluation of engineer support of mobility as an integral part of future mobility studies.

118. The mobility performance of the current standard mobility fleet (including the M151A2) is basically homogeneous and adequate to support current combat vehicles and presently perceived needs for their support.

> Recommendation: No further piecemeal changes from standard to higher mobility vehicles in the combat support fleet should be made unless and until operational needs for higher mobility are defined by scenario play under more demanding threat conditions.

119. Performance of all vehicles in the standard mobility fleet in dune-sand desert terrain is inadequate. This situation can be vastly improved by fitting proper tires for this service.

> Recommendation: Kits should be developed and stockpiled to provide rapid field and depot fitting of suitable tires and wheels and possibly power steering and rapid tire inflation and deflation systems for all vehicle types in the standard mobility fleet on a timely basis, whenever vehicles are assigned to areas where dune-sand operation may be required.

120. The high-mobility fleet designated in this study is not sufficiently homogeneous in performance to constitute a viable combat support fleet. The GOER vehicles are essentially special-purpose vehicles. While these vehicles have considerable usefulness in special

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* While the efficiency of suitable tires and inflations in this type of terrain has been demonstrated as far back as the pre-World War II Egypt Corps, there is at this date no practical evidence that its critical relevance to today's possible problems, or the time required to accomplish suitable changes on the vehicles, is being taken seriously.

circumstances, they are not suitable for the full scope of combat support missions.

Recommendation: Issue of GOER vehicles should be on the basis of special unit needs rather than Army-wide.

121. The performance of the M561, M656, and TDW901 demonstrate that significant increases in combat support potential are currently possible. Because they do not represent a consistent approach to such problems as swimming capability and payload capacities, however, these vehicles do not constitute a suitable basis for the homogeneous fleet (including a compatible high-mobility replacement for the M151A2) that may be required for efficient, effective support of future combat vehicles and doctrine.

Recommendations: Present and projected mobility methodology should be used to define design goals for vehicle and engineer support vehicles, equipment, and doctrine which will lead to a homogenous fleet consistent with future combat and support requirements and an associated combat support doctrine.

Concluding Remarks

122. The HIMO Study exploited and considerably extended the quantitative methodology for mobility evaluation developed under AMC sponsorship from and by WES and TACOM research over many years. It has established terrain, machine, and performance data bases that will be of value to studies for years more. The engineering-based quantification that the mobility methodology provides has created a new, consistent communications link in this field across commands, rank, and time. The specific experience and momentum of the HIMO Study can be directly applied to the timely resolution of many other current mobility-related problems.

123. The mobility methodology per se is well advanced but not yet completed, however. Some parts of the Army Mobility Model, which is the key element of the methodology, remain to be validated. Every new application, including this one, reveals new areas in which the model needs refinement or extension. Acceptance of the methodology leads to important new questions from potential users--about combat vehicle

agility and mobility-RAM-D relations, for example. For their reliable, credible treatment, these questions require engineering research on terrain-vehicle-man interactions, which has not yet been conducted or even funded.

124. In addition, results of mobility methodology application are, correctly, highly sensitive to the terrain and environment described to it. The ultimate realism and correctness of the answers from the methodology accordingly depend on the realism and correctness of the data describing the operational environment. The terrain data base begun as part of the HIMO Study and the methods for its development should be verified and extended to cover other sensitive world areas and other mobility-related activities.

125. An important by-product of the study has been the demonstration of a general, credible procedure by means of which the quantitative engineering approach can be developed and applied to aid in the resolution of complex operational problems involving men, machines, and the vagaries of real world operational environments. The Army has many more design, acquisition, and doctrinal problems to which a similar scenario-oriented quantitative approach is now in order. The mobility methodology can constitute not only an exmaple but also a solid foundation for developing these similar approaches in many related critical areas.

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APPENDIX A: BRIEF DESCRIPTION OF THE AMC MOBILITY MODEL (AMM) AS USED IN THE HIMO STUDY

1. The version of the AMC Mobility Model (AMM) used to predict vehicle speed for the HIMO Study was the first-generation model, AMC-71,[3] with a number of significant improvements in the predictive algorithms that have since been incorporated in the second-generation version (AMC-74) published in 1975.[5,10] The changes in overall program coding (made largely to improve program modularity and transparency) and the significantly revised minor obstacle-negotiation treatment included in AMC-74 were not used, however. The following brief description applies specifically to the intermediate version used in the HIMO Study, which will be referred to as AMC-74X.

2. The gross structure of AMC-74X is shown in Figure A1. Principal elements are three independent computational modules, each comprised of analytical relations derived from laboratory and field research, suitably coupled in the particular type of operation:

- a. The areal patch module, which computes the maximum feasible first-pass speed for a single vehicle in a single areal terrain patch or terrain unit.
- b. The linear feature segment module, which computes the minimum feasible time for a single vehicle, aided or unaided, to cross once a uniform segment of a significant linear terrain feature such as a stream, ditch, or embankment (a linear terrain unit).
- c. The on-road segment module, which computes the maximum feasible first-pass speed of a single vehicle traveling along a uniform segment of a road or trail (a road terrain unit, or road unit).

All three modules draw from a common data base that describes quantitatively the vehicle, the driver, and the terrain to be examined in the simulation. The general content of the data base is shown in Table A1.

3. In AMM the basic approach to representing a complex terrain is to subdivide it into areal patches, linear feature segments, or road segments, each of which can be considered to be uniform within its bounds. This concept is implemented by dividing the range of each individual terrain factor value into a number of class intervals, based

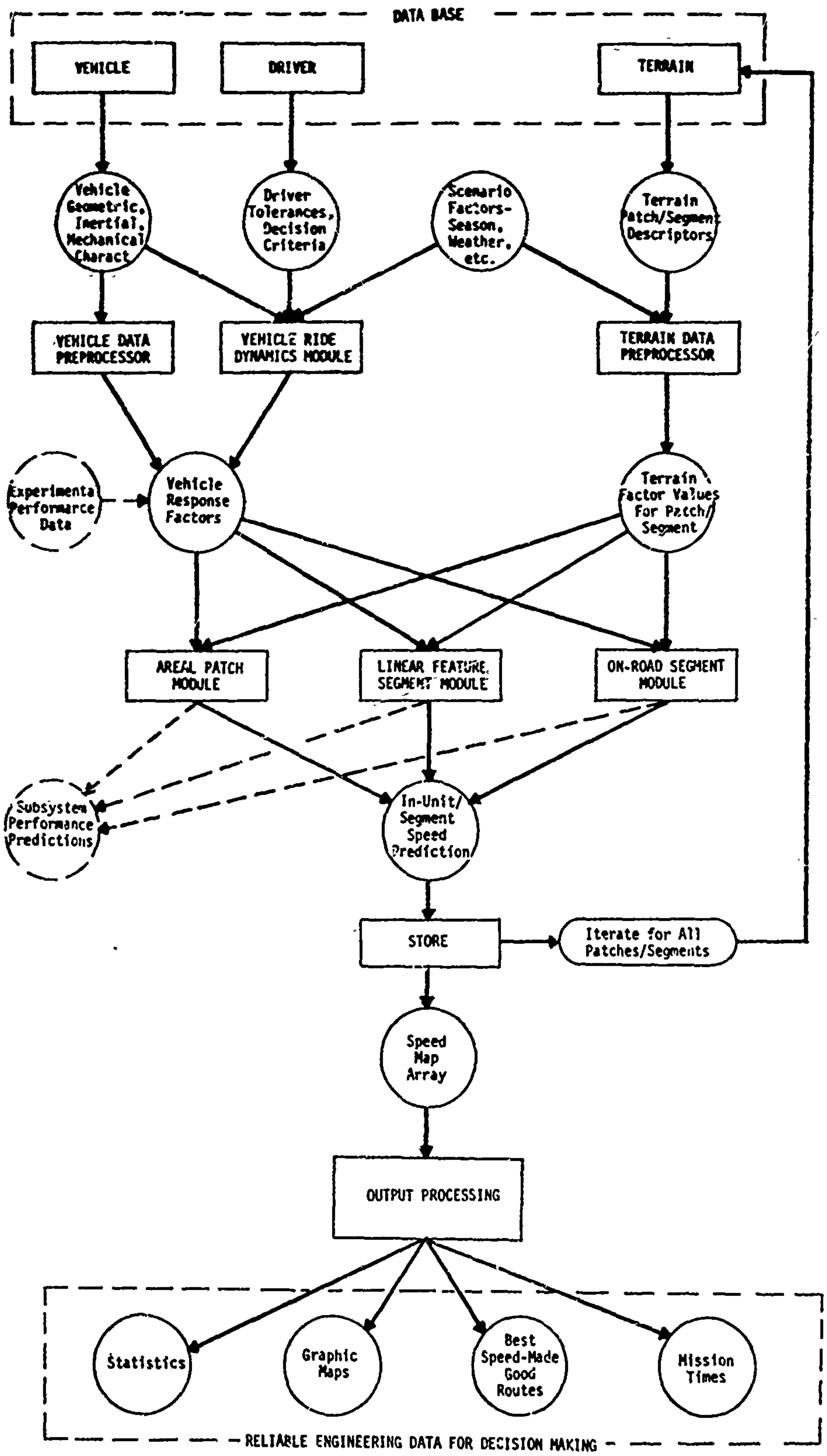

Figure A1. Gross structure of AMC-74X Mobility Model

Table A1

Terrain, Vehicle, Driver Attributes Characterized in AMC-74X Mobility Model Data Base

Terrain	Vehicle Characteristics	Driver
Surface composition Type Strength	Geometric Inertial Mechanical	Reaction times Acceleration and impact tolerances Minimum acceptable speeds
Surface geometry Slope Discrete obstacles Roughness Road curvature	Geometric Inertial Mechanical	Reaction times Acceleration and impact tolerances Minimum acceptable speeds
Vegetation Stem size and spacing Visibility distance	Geometric Inertial Mechanical	Reaction times Acceleration and impact tolerances Minimum acceptable speeds
Linear geometry Cross section Water velocity and depth	Geometric Inertial Mechanical	Reaction times Acceleration and impact tolerances Minimum acceptable speeds

on considerations of vehicle response sensitivity and practical measurement and mapping resolution problems. A patch or a segment, generically referred to as a terrain unit, is then defined by the condition that the class interval designator for each factor involved is the same throughout. A new terrain unit is defined whenever one or more factors fall into a new class interval.

4. For the purposes of the model, each terrain unit is described at any given time by values for a series of 22 mathematically independent terrain factors for an areal unit (including lake and marsh factors), 10 for the cross section and hydrologic characteristics of a linear feature to be negotiated, and 8 to quantify a road segment (Table A2).[18,19,20,21] The areal and road terrain unit data include four values for soil strength (dry, average, wet, and wet-wet seasons) and four seasonal values for recognition distances associated with ambient or roadside vegetation. Further details on the terrain factors used are given in Reference 11.

5. The vehicle is specified in the data base in terms of geometric, inertial, and mechanical characteristics that determine its interactions with the terrain. The complete vehicle characterization as used by the performance computation modules includes measures of dynamic response to ground roughness and to obstacle impact. The model structure permits use at these points of appropriate data derived either from experiments or from a supporting stand-alone simulation[7,8] (paragraph 12 of main text). The required steady-state tractive force-speed relation may also be input directly from proving-ground data, when available and desired. The complete engineering description required for each vehicle is discussed in Appendix B.

6. The driver attributes used in the model characterize the driver in terms of his limiting tolerance to shock and vibration, his ability to perceive and react to visual stimuli affecting his behavior as a vehicle controller, and a minimum acceptable speed that he will strive for even at the expense of comfort and visibility constraints. It has been shown empirically that, in the continuous terrain roughness situation, driver tolerance is a function of the vibrational power being

Table A2

Terrain Data Required for AMC-74X

Terrain or Road Factor	Range
Off Road	
Surface material	
Type, USCS OR OTHER	NA
Mass strength, CI or RCI	0 - >280
Slope, percent	0 - >70
Obstacle	
Approach angle, deg	90 - 270
Vertical magnitude, cm	0 - >85
Length, m	0 - >150
Width, cm	0 - >1200
Spacing, m	0 - >60
Spacing, type	NA
Surface roughness, rms elevations	0 - 10
Stem diameter, cm (8 pairs)	0 - >25
Stem spacing, m (8 pairs)	0 - >100
Visibility distance, m	0 - >50
Water depth, m	0 - >5
Water velocity, mps	0 - >3.5
Water width, m	0 - >70
Linear feature top width, m	0 - >70
Left approach angle, deg	90 - 270
Right approach angle, deg	90 - 270
Differential bank height or differential vertical magnitude, m	0 - >4
Low bank height or least vertical magnitude, m	0 - >6
On Road	
Road type	
Surface material	NA
Type, USCS or other	NA
Surface strength	
Trails, CI or RCI	0 - >280
Other, traction coefficients	0.01 - >0.80
Slope, percent	0 - >70
Surface roughness, rms elevations	0 - >7.6
Curvature, deg	0 - 90
Roadside visibility distance (trails only), m	0 - >50

absorbed by the body.[11] The same work showed that the tolerance limit for representative young American males is approximately 6 watts of continuously absorbed power. More recent measurements in the field have shown that with sufficient motivation young military drivers will tolerate up to 15 watts for periods of up to 20 minutes.[6] In AMC-74X, however, only the 6-watt criterion for limiting vehicle speed due to ride tolerance is used. While a vehicle is crossing a single discrete obstacle, the criterion used to limit speed is a peak acceleration at the driver's seat of 2.5 g passing a 30-Hz filter. Driver reaction time, used in braking calculations, is taken as 0.5 sec, and the minimum acceptable speed is taken as 3 mph.

7. Temporal elements (termed "scenario" factors) that may be input to AMC-74X are the selection of basic climatic conditions (dry, average, wet, wet-wet or specific snow-over-frozen ground conditions), an associated recognition distance in vegetated areas, and associated on-road traction values; whether or not it is raining (which affects soil slipperiness); prevailing ambient visibility limits (due to darkness, rain, etc.); and arbitrary speeds for operations in areas designated as villages, towns, or cities. In addition, in wooded terrain, the driver in AMC-74X (as in AMC-71) is assumed to select the stem and obstacle override or avoid strategy (see paragraphs 11 and 12 below) that will maximize his speed-made-good.* While this indicates ultimate vehicle capabilities, it has recently been found to overestimate both the omniscience and the machismo of real drivers.[12,13]

Main Computational Modules

8. The highly iterative computations required to predict single vehicle, one-pass GO/NOGO or speed performance in each of the many terrain units needed to describe even limited geographic areas are carried out in the three main computational modules.

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* Speed-made-good between two points is the straight-line distance between them divided by total travel time, irrespective of path.

Areal terrain unit (patch) module

9. This module calculates the maximum speed a single vehicle could achieve and maintain while making a first-pass crossing an areal terrain unit. The speed is limited by one or a combination of the following factors:

a. Traction available to overcome the combined resistances of soil, slope, obstacles, and vegetation.

b. Driver discomfort in negotiating rough terrain (ride comfort) and his tolerance to vegetation and obstacle impacts.

c. Driver reluctance to proceed faster than the speed at which the vehicle could be braked to a stop within the visibility distance prevailing in the areal unit (braking-visibility limit).

d. Maneuvering to avoid trees and/or obstacles.

e. Acceleration and deceleration between obstacles if they are to be overridden.

Figure A2 shows a general flow chart of how the calculations of the areal module in AMC-74X are organized. Iterative loops by means of which the strategy for overriding or avoiding obstacles and vegetation to maximize speed-made-good are not shown.

10. The module is entered with the relation between vehicle speed and tractive force on a smooth, level, hard surface and the minimum soil strength the vehicle will require to maintain headway on level, weak soils. The simulation proceeds to check for obstacle-vehicle interferences and to determine the total tractive force required to negotiate terrain impediments and, in turn, the speed limited by motion-resisting forces. This calculation involves the interaction of the soil, slope, obstacle traction, obstacle override, and vegetation impact and override submodels. NOGO is called whenever traction is found to be insufficient to overcome resistances or vegetation impact exceeds tolerable limits.

11. The speed limited by resisting forces is compared with the ride-limiting speed and a visibility-limited speed (computed in the visibility submodel) to find the maximum attainable straight-line speed within the terrain unit. This result is then modified to account for two factors: acceleration and deceleration between discrete obstacles,

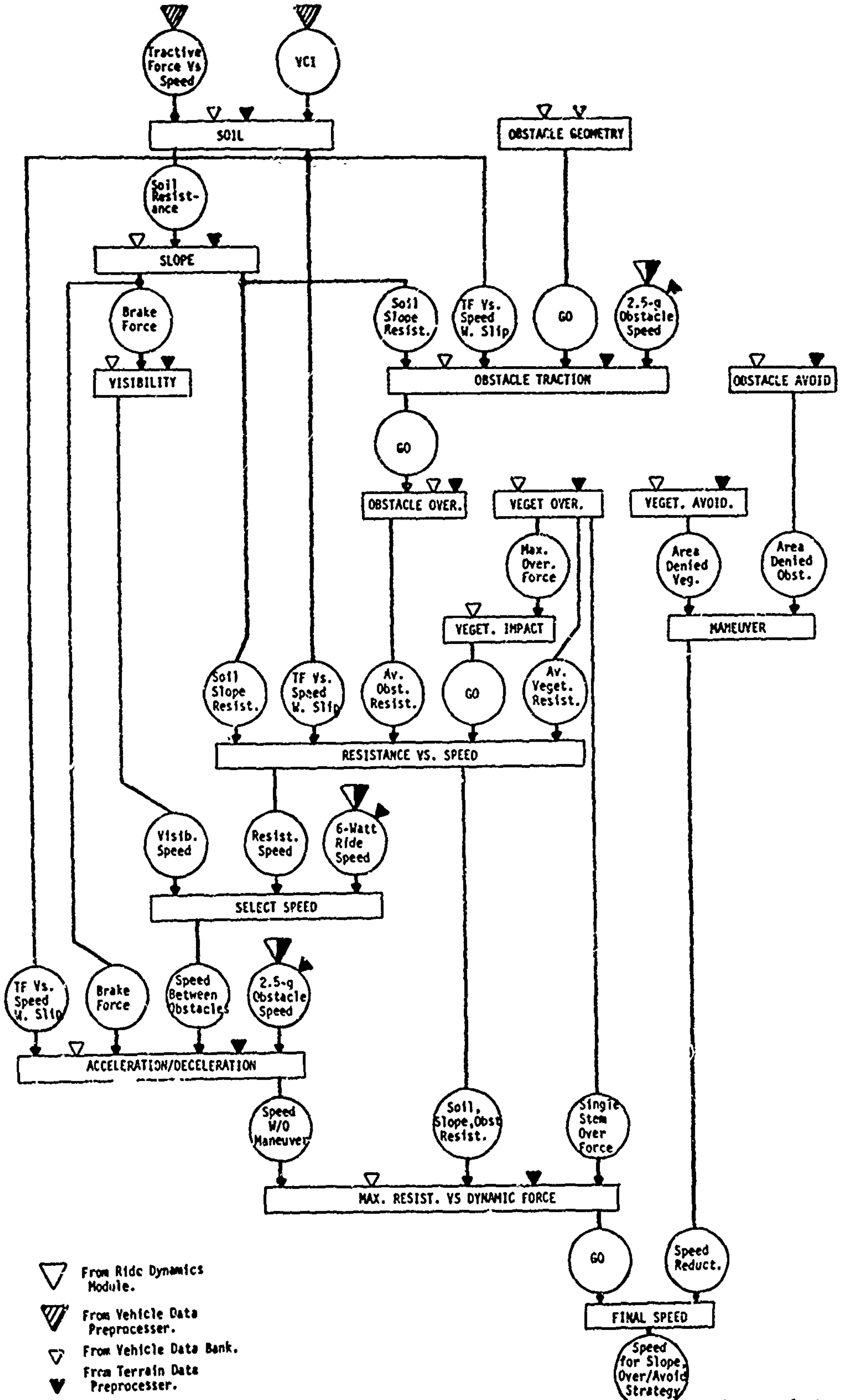

Figure A2. General flow of AMC-74X areal terrain unit module (single loop)

and speed reduction due to maneuvering to avoid vegetation and other obstacles. The final prediction is a terrain unit speed prediction associated with the particular combination of obstacle and vegetation override/avoidance options being considered.

12. The entire terrain unit-speed prediction calculation is iterated over a range of 18 possible override/avoidance options to determine the specific combination producing the highest average speed. The complete process is repeated for the vehicle operating upslope, downslope, and across slope, resulting in three speed predictions. These are averaged, on the assumption that one third of the distance will be traveled in each direction, to produce an omnidirectional mean speed.

13. As compared to the areal module of AMC-71, that of AMC-74X has the following improvements:

a. AMC-74X develops the basic soil-limited tractive force-speed relation by means of an axle-by-axle computation, which allows more direct and rational calculation of the effects of unpowered axles.

b. AMC-74X includes simulation of the effects on vehicle performance of soil slipperiness, which (especially during rainy periods) often limits vehicle slope climbing and such other operations requiring excess traction as obstacle and vegetation override, even though the soil on the slope is strong enough to resist serious rutting.

c. AMC-74X permits prediction of vehicle performance under conditions when the ground is covered by shallow snow and the ground beneath is frozen. Snow depth and snow mechanical characteristics are specified as input data for the areal terrain unit. (Although these parameters may be varied from patch to patch, data for realistic modeling of snow-cover variations over an area were unavailable, so only a uniform snow cover over the entire terrain was played for the HIMO Study.)

d. In AMC-74X, departures in tire inflation and deflection from normal, nominal cross-country values can be realistically accommodated.

14. The most significant change between AMC-71 and the complete second-generation version, AMC-74, not included in AMC-74X (the HIMO version), is in the handling of interference checks and resistance calculations related to those minor discrete obstacles found in areal

terrain units and characterized as a part of the data for each areal unit. In both AMC-71 and AMC-74X, checks for interference between the vehicle and an obstacle are made at a limited number of vehicle positions during the crossing, <u>not</u> including any trailer. It is possible that some immobilizing interferences for large semitrailer rigs are not identified.

15. Perhaps of greater significance in both AMC-71 and AMC-74X, the motion resistance increment due to obstacles is computed on a simple energy basis and assessed as an average value throughout the areal terrain unit. This has given apparently reasonable results for relatively compact, all-wheel-drive vehicles, but it understates the peak traction requirements that will often control the performance of semitrailer rigs with their heavily loaded, unpowered trailer axles. As a result, it is probable that some semitrailer traction failures due to obstacles are not called.

16. Revisions incorporated in the complete AMC-74 model are expected to make predictions of obstacle performance for vehicles with trailers more realistic. The revised computational routines were not operational at the time the HIMO predictions were required and accordingly are not a part of AMC-74X.

17. Some error is also expected in relation to semitrailer rig operation in wooded terrain and perhaps on narrow trails, where their maneuverability is overestimated. (Relations used in the model were developed from single-vehicle data.) Finally, a good driver of such a rig emphasizes maintaining momentum, often at the temporary expense of ride or braking constraints, so that in suitable conditions speeds predicted on the basis of the driver behavior modeled in AMC-71 and AMC-74X may be low. None of these error sources is corrected in the complete AMC-74 model, pending further work.

18. Although the limitations outlined in paragraphs 14, 15, and 17 lead to significant errors in predicting semitrailer rig performance in bad terrain, such predictions can still be useful in comparative performance evaluations of various such rigs, where the errors will be of the same order for all candidates. The predictions cannot be considered as

a reliable basis for comparing the relative performance of semitrailer combinations with that of single vehicles, however, as is required in this study. Predicted semitrailer rig performance in severe terrain is probably considerably optimistic.

Linear-terrain-unit (feature segment) module

19. In the context of AMM, a linear feature is a distinct terrain element such as a stream, a man-made drainage ditch, a canal, an escarpment, or a highway or railroad embankment that is a potential barrier to vehicle movement normal to its characteristic length. Most such features are represented by lines on a good 1:50,000 topographic map of an area.

20. The linear-feature-crossing module used in AMC-74X first determines whether or not the vehicle can negotiate the obstacle from one side to the other along the cross section described for the linear terrain unit.[4,5,14] Resistance is compared to available traction while the vehicle is mounting each bank (or flank, if an embankment), and possible interferences are checked. If the feature is wet (a river, stream, canal, etc.), water depth and any current are checked against the vehicle fording or swimming capabilities. When none of these factors is NOGO, a crossing time is developed from computed bank negotiation and swim or ford times.

21. When one or more NOGO situations are identified along the crossing path, the severity of each is recorded in terms of degree and location of interference, traction deficit, or, in the case of insufficient fording or swimming capabilities, a special flag. A delay time is then assessed according to the type and severity of all NOGO's and the size of the vehicle (which impacts the level of recovery effort or other assistance required). For the HIMO Study predictions, a maximum crossing time of 60 min was used for any single crossing on the premise that whereas a single vehicle on its own might be delayed much longer, in a continuous military operation engineer support would be arranged or bypasses found that would limit delays for multivehicle operations to a reasonable level.

On-road unit (segment) module

22. The on-road unit module calculates the maximum speed a vehicle can be expected to maintain along a nominally uniform stretch of road, termed a road unit. Travel on superhighways, primary or secondary roads, and trails is identical by specifying a road type and a surface condition factor. From these, values of tractive and rolling resistance coefficients for wheeled and tracked vehicles on paved-surface roads are determined by a table look up. For trails and soil-surfaced teritary roads, surface condition is specified in terms of cone index (CI) or rating cone index (RCI). Traction, motion resistance, and slip are computed using the one-pass soil submodel of the areal module, with scenario weather factors (including snow) used in the same way as in making off-road predictions. (Traffic effects on trail soils are approximated by deliberately assigning values for trail soil strengths that are lower than would be expected. See Appendix C, paragraph 12.)

23. The structure of the road unit module, though much simpler, parallels that of the areal terrain unit module. Separate speeds are computed as limited by available traction and countervailing rolling and grade resistances, by ride dynamics (absorbed power),* by visibility and braking, and by road curvature per se (a feature not directly considered in the areal module). The least of these five speeds is assigned as the maximum for the road unit for the assumed direction of travel relative to the specified grade.

24. The basic curvature-speed limits are derived from the American Association of State Highway Officials (AASHO) experience data for the four classes of roads[15] under dry conditions and are not vehicle dependent. These are appropriately reduced when traction conditions are reduced. On trails, where curvature and roadside vegetation in a road unit combine to reduce forward recognition distance below that specified for ambient

* Trails tend to have less high-frequency and more low-frequency components at a given root mean square (rms) profile elevation than natural terrain because of the effects of traffic. As a result, a ride speed versus rms roughness relation for road and trails is used which is different from that used for cross-country travel.

visibility conditions, the reduced recognition distance is used in computing the visibility and braking-speed limits for the unit.

25. The module computes vehicle performance in a road unit both up and down the characteristic grade for the unit and determines the bidirectional average on the basis of equal travel distances in each direction.

26. Features of the AMC-74X road unit module not found in the AMC-71 version used to make performance calculations for the 1972 DA WHEELS Study[9] are:

_a._ Capability to predict performance under degraded traction conditions (wet, snow-packed, or ice- or snow-covered roads).

_b._ Consideration of combined road curvature and roadside vegetation on narrow trails as a possible speed-limiting factor.

Features, included in the complete AMC-74 but not incorporated in AMC-74X, are the effects of altitude on power train perf ~ce, of aerodynamic and curvature resistance, and of road width per se on overall performance.

AMM (AMC-71) validation

27. A major part of AMM development has been validation of the entire model and of its component parts in a systematic field validation program using actual vehicles and natural terrain.[12,13] Validation testing of AMC-71 was conducted principally with four standard Army vehicles, M151A1, M35A1, M113A1, and M60A1, over a variety of cross-country courses at Fort Sill, Oklahoma; Yuma, Arizona; Eglin Air Force Base, Florida; Houghton, Michigan; and Fort Knox, Kentucky. Overall test results encompass measured speeds over the range from 2-30 mph. Comparisons of measured and predicted speeds show that the areal terrain module of the AMC-71 version of AMM,[3] including the supporting ride dynamics module,[7,8] predicts speeds which are generally high by about 1-3 mph. Part of the error can be traced to lack of a routine in AMC-71 to account for vehicle acceleration and deceleration across terrain unit boundaries when travel time along a specified path is involved. Analysis of the remaining deviations indicates that the major intrinsic

model weaknesses are associated with criteria for and logic of driver behavior, particularly in forested terrain.

28. Validation of the on-road and linear-feature-crossing modules is incomplete, as is validation of the areal terrain module in relation to tractor-trailer combinations. The validation program is continuing but at a much reduced pace. Work in the near future will emphasize examination of the new features introduced in AMC-74 (paragraphs 13 and 14). These features were developed from reasonable data bases but are presently unvalidated.

Output

29. For each vehicle in each terrain unit and condition encountered in each study area, AMC-74X was used to predict omnidirectional speed in areal units and bidirectional speed in road units and to assess crossing times for negotiating each linear terrain unit.* These data, running to over one million individual speed predictions, were stored in computer files for subsequent processing to link travel times, to statistics expressing vehicle-terrain condition compatibility, and to areal terrain speed and speed comparison maps.

30. NOGO's identified in the areal and road terrain (as on steep, wet trails) were recorded as zero-speed terrain units. Time penalties for areal and road unit NOGO's were subsequently assessed at the time the terrain unit predictions were assembled to predict job travel times.

31. Reasons for NOGO or factors limiting speeds in GO situations were also developed in the course of making areal and road unit predictions. These diagnostic data are saved in computer files to develop statistics indicating, for each study area, the relative occurrence of various NOGO reasons and speed-limiting factors.

32. A small sample of the output (speeds and diagnostic flags) is shown in Figure A3. The distance data were normalized and terrain units

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* In both the areal and road performance predictions modules, travel in areas flagged in the terrain data as being villages, towns, or cities was set at arbitrary values input as scenario data (20, 15, and 10 mph, respectively, under dry conditions, were used in the present study). These speeds are reduced in the same way as road curvature-speed limits when traction is reduced.

Terrain Unit	In Unit	Accum	In Unit	Accum	Speed On Slopes, mph Up	Level	Down	Factor Limiting Speed On Slopes Up	Lv	Dn
1136	0.2	54.3	7.5	10.9	7.5	7.5	7.5	10	10	10
658	0.2	54.5	7.5	10.9	6.5	8.1	8.1	6	10	10
681	0.1	54.6	7.5	10.9	7.5	7.5	7.5	8	8	8
522	0.1	54.7	7.5	10.9	4.4	11.3	11.3	6	5	5
873	0.1	54.8	7.5	10.9	7.5	7.5	7.5	5	5	5
453	0.1	54.9	7.5	10.9	7.5	7.5	7.5	5	5	5
160	0.1	54.9	7.5	10.9	7.5	7.5	7.5	10	10	10
248	0.1	55.0	7.5	10.9	7.4	7.5	7.5	9	8	8
605	0.1	55.1	7.5	10.9	5.0	10.0	10.0	6	5	5
1427	0.	55.1	7.5	10.9	6.8	8.0	8.0	6	5	5
955	0.	55.1	7.5	10.8	7.4	7.6	7.6	10	10	10
173	0.	55.2	7.5	10.8	7.5	7.5	7.5	5	5	5
636	0.	55.2	7.5	10.8	5.0	10.0	10.0	6	5	5
1558	0.	55.2	7.5	10.8	7.5	7.5	7.5	8	8	8
225	0.	55.2	7.5	10.8	7.5	7.5	7.5	10	10	10
219	0.	55.2	7.5	10.8	7.5	7.5	7.5	10	10	10
58	0.2	55.4	7.4	10.8	6.4	7.9	7.9	6	8	8
540	0.	55.4	7.4	10.8	7.2	7.5	7.5	10	10	10
615	0.	55.4	7.4	10.8	6.4	8.0	8.0	9	5	5
1323	0.	55.4	7.4	10.8	6.6	7.9	8.0	10	10	10
411	0.	55.4	7.4	10.8	7.1	7.5	7.5	6	5	5
1102	0.1	55.6	7.3	10.8	7.3	7.3	7.3	8	8	8
218	0.1	55.7	7.3	10.8	6.8	7.6	7.6	10	10	10
834	0.1	55.7	7.3	10.8	7.3	7.3	7.3	5	5	5
1165	0.1	55.8	7.3	10.8	5.4	9.0	9.0	6	5	5
1398	0.	55.8	7.3	10.8	7.3	7.3	7.3	5	5	5

Off-Road Terrain Unit No.

Distance In-Unit

Basic In-Unit and Accumulative Speed Predictions (mph)

Reasons For NOGO or Speed Limit

Figure A3. Partial listing of cross-country speeds in terrain units (M151A2)

ordered according to decreasing in-unit omnidirectional speed. Ordering and accumulation of distance and associated average speed are done in an output routine preparatory to developing the off-road speed profile.

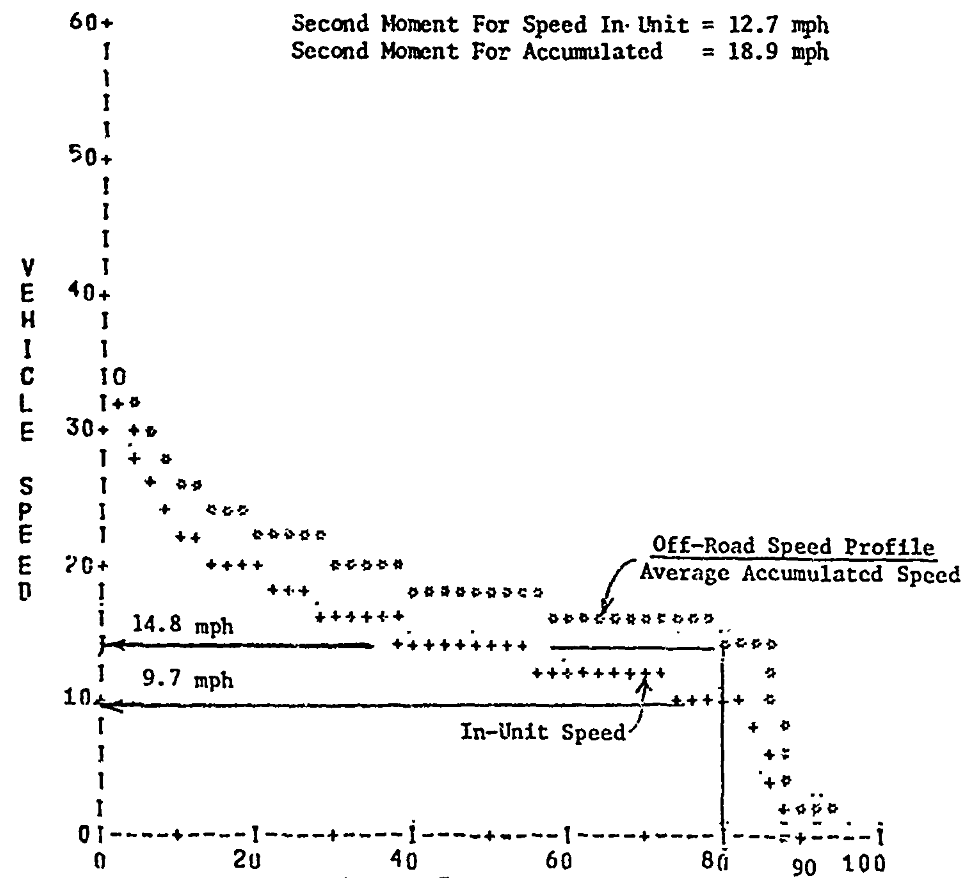
33. The off-road speed profile conveys a complete mission independent statistical description in the total off-road terrain sample in all aspects save spatial distribution. The profile indicates the average speed a single vehicle can sustain as a function of the percentage of the total area under consideration that it is able to avoid, under the assumption that at each level it avoids those areas posing the greatest impediment to its motion. In constructing the off-road speed profile, NOGO distances are assumed to be traversed at 0.1 mph. Figure A4 shows the completed speed profile data for a specific vehicle (M151A2) in a specific area and condition as a computer output in tabular form ("accumulated speed") and as a rough typewriter plot for quick visualization. In the case illustrated, the vehicle can average 14.8 mph throughout 80 percent of the specified areal terrain, provided the 20 percent that is avoided is the most difficult 20 percent. The speed for 90 percent of an area, designated V_{90}, was used in the 1972 DA WHEELS Study as a primary index of vehicle off-road performance in a given area and condition.

34. The output shown in Figure A4 also gives the basic speed predictions for each terrain unit and associated area again organized in order of decreasing speed ("in-unit speed"). These data show the minimum speed that a vehicle can achieve as a function of the percentage of the total area that it avoids, assuming, as earlier, that it avoids the most difficult terrain; for example, the vehicle characterized in Figure A4 can go 9.7 mph or faster in the best 80 percent of the area. The output is completed by the percentage of the area that is NOGO (13.4 percent) and two experimental indices of mobility-speed performance (under study by TACOM) which are the second moments of the in-unit speed profile and of the off-road (accumulated) speed profiles about the Y-axis (12.7 and 18.9, respectively).

35. Figure A5 illustrates the on-road speed profile for the same vehicle operating on the roads and trails within the same area (with no

GERMANY TRAVERSE QUAD-5520 AREAL PREDICT

VEHICLE NO. 7 SCENARIO CONDITION 2 NUMBER OF UNITS 622 TOTAL



PERCENT DISTANCE "NO-GO" = 13,4

PERCENT TOTAL DISTANCE

	X=0	2	4	6	8
X	41.2	33.6	29.3	25.4	23.6
1X	22.6	21.4	20.5	20.0	19.6
2X	19.2	19.0	18,3	17.3	16,8
3X	16.0	15.4	15,0	15.0	15.0
4X	14.9	14.7	14,5	14.2	13.9
5X	13.5	13.4	13,1	12.8	12.7
6X	12,4	12.3	12,0	12.0	12,0
7X	11.8	11.4	10.9	10.2	9.9
8X	9.7	9.1	7,6	5.9	0.1
9X	0.1	0.1	0.1	0.1	0.1
10X	0.1				

SPEED IN UNIT

PERCENT TOTAL DISTANCE

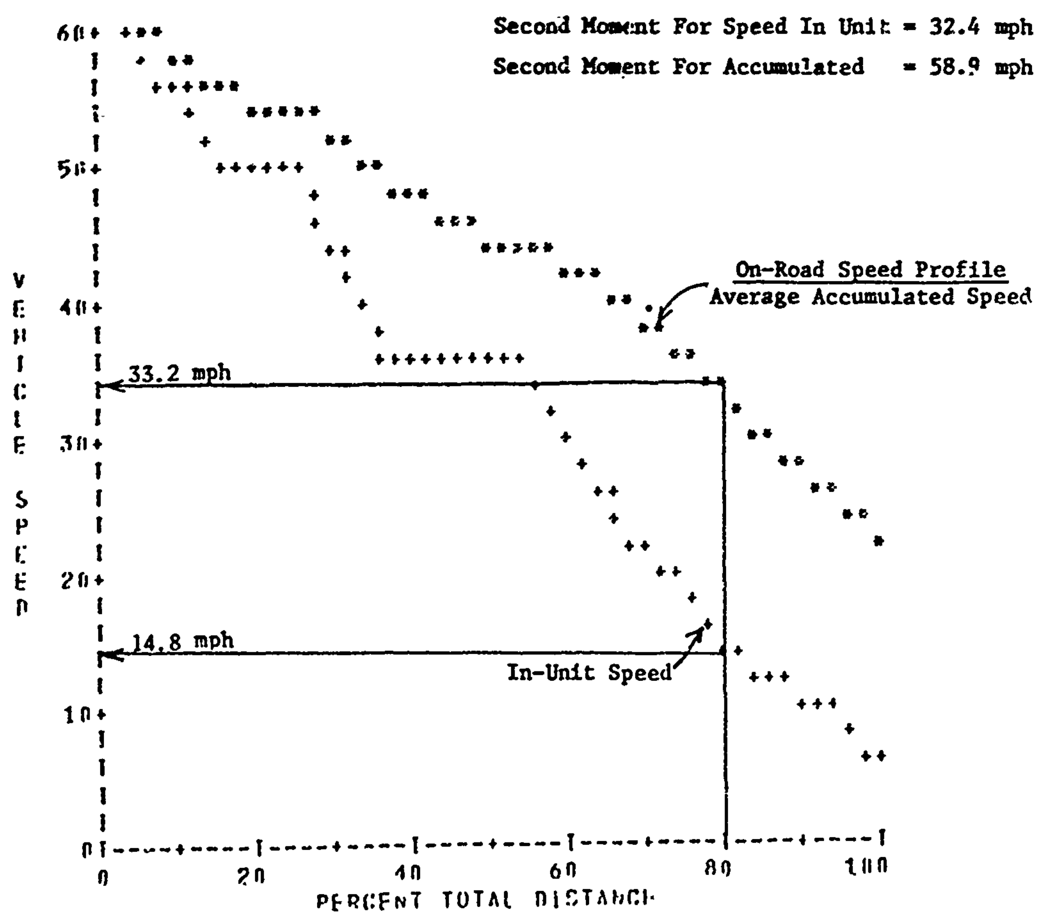
	X=0	2	4	6	8
X	41.2	33.6	31.3	29.1	27.5
1X	26.3	25.4	24,5	23.9	23.3
2X	22.8	22.4	22,0	21.5	21.1
3X	20.7	20.2	19,8	19.5	19.2
4X	18.9	18.7	18.4	18.2	17.9
5X	17.7	17.5	17.3	17.1	16.9
6X	16.7	16.5	16.3	16.1	16.0
7X	15.8	15.6	15.4	15.2	15.0
8X	14.8	14.6	14.3	13.6	4.4
9X	2.2	1.5	1,2	1.0	0.8
10X	0.7				

ACCUMULATED SPEED

Figure A4. Off-road speed profile data

GERMANY TRAVERSE QUAD-5520 ON ROAD PREDI

VEHICLE NO. 7   SCENARIO CONDITION 2   NUMBER OF UNITS 1461   TOTAL



THERE IS NO "NO-GO" DISTANCE

PERCENT TOTAL DISTANCE

	X=0	2	4	6	8
X	61.8	61.8	61.6	58.4	55.4
1X	55.3	55.1	52.3	50.7	50.7
2X	50.7	50.7	50.7	50.4	46.8
3X	44.2	43.1	40.4	36.0	36.0
4X	36.0	36.0	36.0	36.0	36.0
5X	36.0	36.0	35.2	34.8	31.3
6X	30.2	27.8	26.3	25.4	22.0
7X	21.2	19.6	19.0	17.2	15.5
8X	14.8	13.2	12.7	12.6	11.0
9X	11.0	11.0	9.1	8.5	6.2
10X	5.7				

SPEED IN UNIT

PERCENT TOTAL DISTANCE

	X=0	2	4	6	8
X	61.8	61.8	61.7	60.5	59.2
1X	58.4	57.8	56.9	56.1	55.4
2X	54.9	54.5	54.2	53.9	53.3
3X	52.6	51.8	51.0	49.8	48.9
4X	48.0	47.2	46.6	46.0	45.5
5X	45.0	44.6	44.1	43.7	43.1
6X	42.5	41.8	41.0	40.3	39.3
7X	38.4	37.4	36.4	35.4	34.3
8X	33.2	32.0	30.9	29.9	28.7
9X	27.8	26.9	25.8	24.7	23.3
10X	22.0				

ACCUMULATED SPEED

Figure A5. On-road speed profile data

traffic flow problems considered). The accumulated and in-unit speed curves indicate the degradation of probable on-road performance as more and more secondary roads and trails are included in the total travel.

36. Figures A6 and A7 show the output of the diagnostic analyses for the same vehicle for which speed profiles were given in Figures A4 and A5, operating in the same condition over all areal terrain and all roads and trails in the same specific area. The off-road diagnostics show that the 13.4 percent of the area that is NOGO for this vehicle is made so by vehicle and obstacle interferences and that the principal speed-limiting factors in GO areas are due to maneuver requirement (27.6 percent) and visibility/braking limits (24.0 percent). On-road speed is limited primarily by road and trail roughness (40.1 percent) and road curvature (39.5 percent). Note that, since all reasons always add to 100 percent, changes in vehicle characteristics that might reduce ride severity, and hence reduce the percentage of travel where ride speed was the limitation, will increase the percentages attributable to one or more other factors. Corollary to this, the improvement in overall performance resulting from even a major ride improvement might be small.

37. The off-road diagnostics, as output directly by the computer program, are consolidated for presentation and discussion in Appendix D of this report as follows:

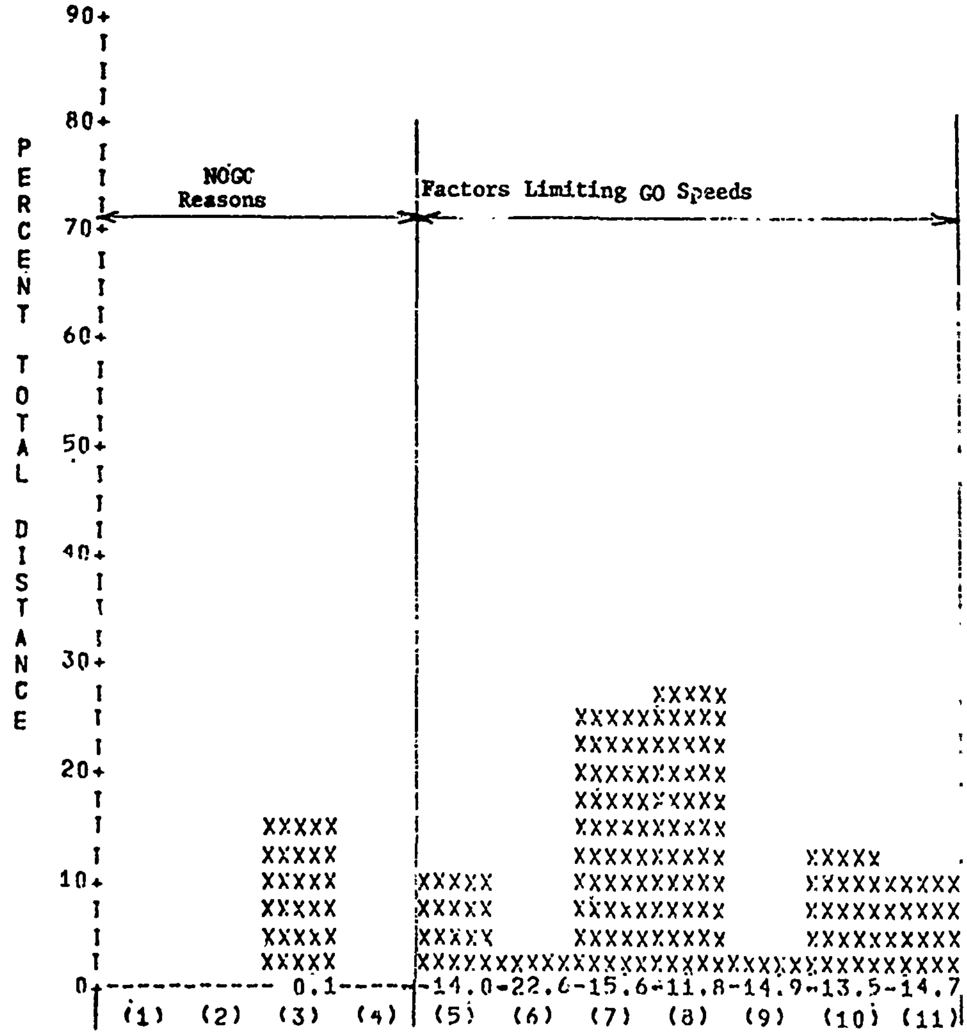
NOGO reasons:	Traction (reasons 1 and 2) Obstacles and vegetation (reasons 3 and 4)
Speed limits:	Ride (reason 5) Power (reasons 6 and 9) Visibility or braking (reason 7) Obstacles and vegetation (reasons 8 and 10) Urban areas (reason 11)

AMC-74X Modeling Limitations and Application Assumptions that Impact Detailed Predictions Used in the HIMO Study

38. Like any simulation, AMC-74X does not completely reproduce the real world. To aid in interpreting the predictions and other study results, several limitations of AMC-74X and some assumptions made to

GERMANY TRAVERSE QUAD-5520 AREAL PREDICT

VEHICLE NO. 7 SCENARIO CONDITION 2 NUMBER OF UNITS 622 TOTAL



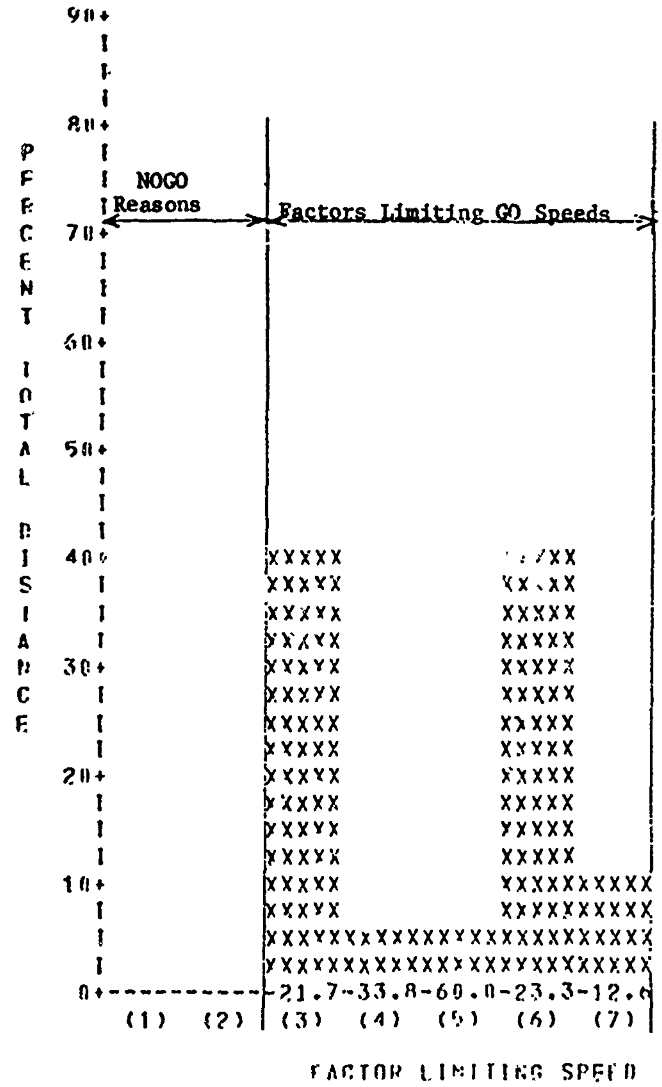
FACTOR LIMITING SPEED

	FACTOR LIMITING SPEED	% AREA LIMITED	AVERAGE SPEED
(1)	INSUFFICIENT SOIL STRENGTH	0.	-
(2)	INSUFFICIENT TRACTION	0.	-
(3)	OBSTACLE INTERFERENCE	13.4	NO-GO
(4)	COMBINATION OF TERRAIN FACTORS	0.	-
(5)	ROUGHNESS (RIDE) SPEED LIMIT	10.6	14.0
(6)	SOIL/SLOPE RESISTANCES	1.6	22.6
(7)	VISIBILITY LIMIT	24.6	15.6
(8)	MANEUVER PROBLEM	27.6	11.8
(9)	VEGETATION RESISTANCES	0.9	14.9
(10)	AC/DC BETWEEN OBSTACLES	12.3	13.5
(11)	EXTERNAL (URBAN) SPEED LIMIT	9.5	14.7

Figure A6. Off-road diagnostics analysis

GERMANY TRAVERSE QUAD-5520 ON ROAD PREDI

VEHICLE NO. 7   SCENARIO CONDITION 2   NUMBER OF UNITS 1461   TOTAL



FACTOR LIMITING SPEED		% AREA LIMITED	AVERAGE SPEED
(1)	INSUFFICIENT SOIL STRENGTH	0.	-
(2)	INSUFFICIENT TRACTION	0.	-
(3)	ROUGHNESS (RIDE) SPEED LIMIT	40.1	21.7
(4)	SOIL/SLOPE RESISTANCES	5.5	33.8
(5)	VISIBILITY LIMIT	5.4	60.0
(6)	ROAD CURVATURE	39.5	23.3
(7)	EXTERNAL (URBAN) SPEED LIMIT	9.5	12.6

Figure A7. On-road diagnostics analysis

facilitate its application to the HIMO Study are summarized here.

Areal terrain predictions

39. Soil strengths characterizing areal terrain units are assumed to be uniform to depths of 30 in. In most places soil strength will increase with depth. This fact is recognized in the field-oriented WES-vehicle cone index (VCI) system for predicting vehicle performance[16] in which the field strength of a soil in relation to a vehicle is measured in deeper layers for larger vehicles. The assumption of soil strength uniformity with depth makes the soil component of the terrain relatively somewhat less severe to small vehicles such as the M151A2 and more severe for large vehicles such as the M520E1 than it might in fact be in any given area. This bias is accentuated for the M520E1 because, with its large-diameter tires and high-ground clearance, it can exploit the soil strength to somewhat greater depths than can more conventionally configured vehicles. This assumption may result in some increase in NOGO calls for all larger vehicles as compared with the smaller ones, but the bias is considered acceptably small and the trends shown by the data are considered valid.

40. Ride-speed limits used in AMM are based on driver absorbed power resulting from vertical motions and accelerations only. On-going research shows that driver perception of ride severity is also sensitive to fore-and-aft and side-to-side motions. Field measurements indicate that perhaps 20 percent of off-road roughness situations significantly excite these additional motions. Use of vertical absorbed power only will, in general, result in overestimating the ride speed in these situations. In addition, in any given terrain situation in which vertical absorbed power is an insufficient measure of ride severity, the suspension of one vehicle may amplify fore-and-aft or side-to-side terrain inputs, whereas the suspension of a second vehicle might mitigate them. Although the two horizontal responses to terrain roughness will tend to be less in vehicles having good vertical ride characteristics, and vice versa, the relation is not necessarily close. As a result, predicted speeds of different vehicles, when under 6-watt vertical absorbed power ride-speed control, may actually result not only

in higher three-dimensional absorbed powers but also in somewhat different levels for different vehicles. The effects of this on the study results are considered negligible, but the flag is raised.

41. Modeling of semitrailer rig performance in areal terrain characterized by having significant discrete obstacles probably does not identify all interference or traction immobilizations. Performance of semitrailer rigs in forested areas may also be overestimated, but calculated visibility- or braking-speed limits and ride-speed limits may tend to be low because of vehicle-associated driver behavior, which differs from that assigned to AMM (paragraphs 14, 15, and 17). Failure to call all semitrailer rig NOGO's in obstacle or forest situations overstates the off-road performance of the M818-M127A1C combination in relation to other vehicles in the study. The degree of distortion produced is unknown, but off-road performance figures for this rig must be considered suspect.

42. Soil slipperiness and snow performance modeling used in AMC-74X are presently unvalidated by field tests (paragraphs 13, 14, and 28).

Road performance predictions

43. Vehicle performance on trails and the effects of associated traffic were obtained by using one-pass prediction algorithms with appropriately reduced surface strength values (Appendix C, paragraph 12).

44. Field validation of the road performance computation module is incomplete (paragraph 28).

Linear-feature-crossing predictions

45. The module that computes linear-feature-crossing times is as yet largely unvalidated in field tests (paragraph 28).

Application assumptions

46. A number of capabilities of AMM were deliberately not exploited. All of the following assumptions relate to such options and were made because of the great amount of additional computer use that would otherwise have been involved. None are thought to affect the results materially in relation to their use for purposes of the HIMO

Study.

a. Predictions for all vehicles were made with each vehicle carrying its rated payload and (for the wheeled vehicles) operating with recommended cross-country tire inflation pressures (or in sand areas at sand pressures). For the vehicles and situations in the study, speeds when running empty would be generally 5-10 percent higher. Since full job travel required will often involve one-way travel with no load, speeds based on carrying rated payload at all times are conservative.

b. On the premise that each route usually would be covered in both directions, the speed assigned for each road unit was the bidirectional average (paragraph 25).

c. The off-road speed assigned for each vehicle in each terrain unit (and condition) is the omnidirectional average (paragraph 12).

d. Travel times were determined by simply adding times in all component terrain units, based on total distance in each terrain unit and the average off-road or on-road speed predicted for it, i.e., no acceleration or deceleration (AC/DC) effects across terrain unit boundaries were considered. Comparisons of speed predictions for a vehicle on a given traverse, made with and without AC/DC effects, generally show that the latter are 5-10 percent higher. The amount of difference is not greatly vehicle dependent, so that use of predictions without modifications for AC/DC is not considered to distort the relative results. The absolute error involved tends to offset that resulting from basing job time assignments on full-load speeds (paragraph 40a).

e. Snow cover, examined as a condition in the West Germany study area, was considered to be of uniform depth and physical characteristics over all roads and trails (paragraph 13c).

APPENDIX B: TERRAIN MOBILITY MAP PREPARATION

1. Realistic, credible specification of the terrain in the study areas, in the terms required by AMM to predict vehicle performance, was a critical element of the HIMO Study. Prior to the study, areas characterized for various mobility research purposes[11] were relatively small in comparison[17] with those determined to be required for the study play of two brigades (approximately 30 by 100 km). Preparation of the requisite data for the two selected study areas absorbed a major part of the effort by the WES/TACOM mobility research team.

2. To predict the speed of a given vehicle in a given nominally homogeneous patch of areal terrain or along a given homogeneous stretch of road, or the time required to cross a given linear terrain feature, the corresponding terrain unit must be characterized in terms of a large number of engineering measurements. A patch of areal terrain requires specification of 22 numbers, a stretch of road 8, and a linear feature crossing site 10 (Table B1).* The kinds and degrees of resolution of data required are not found in any conventional sources, especially for areas large enough for the conduct of meaningful mobility studies; therefore, special maps containing the required data must be prepared. This is done by consulting data sources on the area in question and inferring from their total informational content a series of specific values for the mobility factors needed by AMM. This process is described here briefly.

3. The mobility terrain data were prepared for the Mid-East and the West Germany study areas in the form of areal and linear

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* The complete terrain data include alternative values for some factors, which reflect seasonal differences, so that the nuber of values per terrain unit that constitutes maps is larger. Specific values are selected at run time by specification of appropriate "scenario" factors (Appendix F, paragraph 7). In addition, when, as is normally the case, the predictions are to be aggregated in statistical form or output in map form, data on percentage of area occupied or geographic location of each terrain unit are required at the conclusion of all single-terrain-unit prediction runs. These additional data, however, are not a part of the basic terrain data base used by AMM per se.

Table B1

Terrain Data Required for AMC-74X

Terrain or Road Factor	Range
Off Road	
Surface material	
Type, USCS or other	NA
Mass strength, CI or RCI	0 - >280
Slope, percent	0 - >70
Obstacle	
Approach angle, deg	90 - 270
Vertical magnitude, cm	0 - >85
Length, m	0 - >150
Width, cm	0 - >1200
Spacing, m	0 - >60
Spacing, type	NA
Surface roughness, rms elevations	0 - 10
Stem diameter, cm (8 pairs)	0 - >25
Stem spacing, m (8 pairs)	0 - >100
Visibility distance, m	0 - >50
Water depth, m	0 - >5
Water velocity, mps	0 - >3.5
Water width, m	0 - >70
Linear feature top width, m	0 - >70
Left approach angle, deg	90 - 270
Right approach angle, deg	90 - 270
Differential bank height or differential vertical magnitude, m	0 - >4
Low bank height or least vertical magnitude, m	0 - >6
On-Road	
Road type	NA
Surface material	NA
Type, USCS or other	
Surface strength	
Trails, CI or RCI	0 - >280
Other, traction coefficients	0.01 - >0.80
Slope, percent	0 - >70
Surface roughness, rms elevation	0 - >7.6
Curvature, deg	0 - 90
Roadside visibility distance (trails only), m	0 - >50

terrain unit maps of the two areas, digitized to a resolution (cell size) of 127 m east-to-west by 105.83 m north-to-south. The size of the cell at 1:25,000 scale is 1/5 by 1/6 in.; this is the space for two characters on one line in a printout made by a standard high-speed computer printer (10 characters/in., 6 lines/in.). This permits rapid printing of undistorted digitized maps at 1:25,000 scale, with two characters available to display for each cell whatever information (terrain unit code, vehicle speed, reasons for NOGO or speed limits, etc.) is to be mapped. Two-to-one reduction in a copying machine quickly converts these to 1:50,000, the scale of the topographic maps that are basic to the study.

Study Map Concept

4. The maps, produced by inferring the required quantitative mobility terrain data for each cell from available qualitative data describing the cell, are termed study maps. No claim can be made that the specific set of mobility terrain factor values assigned for a given cell on the map will in fact be found in that cell on the ground. What can be claimed for the values is that they are wholly consistent with the available data; that is, if the map shows a forest at some point, there will be depicted at that point in the mobility data a forest that is reasonable for the climate, site, and cultural influences of the area. Again, if the map shows a specific soil type and slope, the soil strength assigned at that point will be consistent with the best information as to what that strength might be, based on soil type, drainage features, land-use practices, and climate.

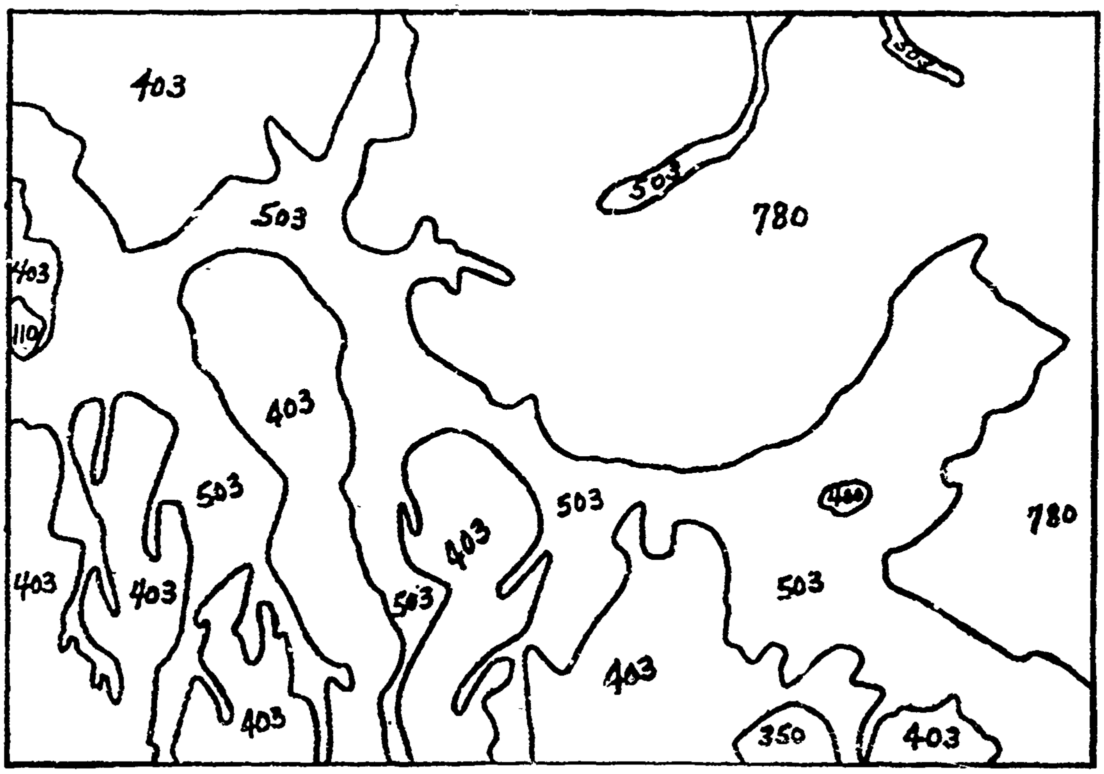
5. The assigned values for mobility factors are subject to errors from two sources. First, the initial mapped data, whether it be on the topographic map or one of the other basic data maps, may be in error; for example, the forest that is shown on the map may have been cut down since the map was printed. Second, the assignment of quantitative values from the available qualitative information may be considerably in error because of limitations in correlation procedures. It can be

asserted, however, that the process will result in a map that is highly representative of the levels and areal distribution of all major mobility influences throughout the area that it purports to depict and is, therefore, suitable for purposes of such studies as HIMO. The maps are not considered to be suitable for tactical use (although they might well be better than anything else available at this time).

Areal Terrain Unit Maps

6. The inferential process for developing areal terrain unit maps begins by assembling in map form available information on many physical aspects of the area. (Soils, surface geology, and gross vegetation maps plus the best available topographic maps were used for the two HIMO Study areas). Numeric codes are established for all information in the legend of each map. By overlaying the several maps at a common scale, they are consolidated into a single map with appropriately expanded legend information. This step is currently implemented in the computer. To do this, discrete areas defined on each basic map are delineated in a manually prepared overlay and by the associated legend information in coded form. In the case of normal topographic maps, information density is so great that two overlays are made, one to extract basic slope data and a second to extract all of the extensive land-use and other useful information that is overprinted on the contours. Figure B1 illustrates a coded land-use map made by manually overlaying a topographic map. The coded legend picks up all information provided in the original map legend for each discrete area.

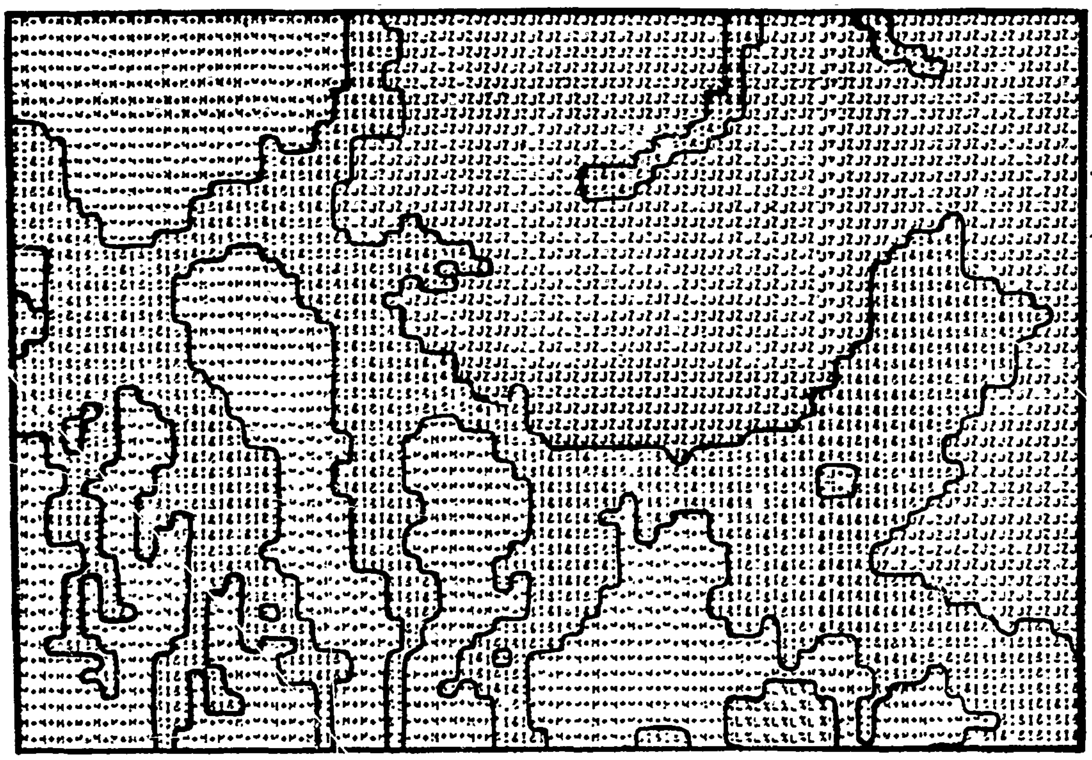
7. Boundaries between differently coded areas on the separate manual overlays are defined by a series of X-Y coordinates automatically generated by a manually operated digitizing line-follower and recorded with the codes on a magnetic tape.. Computer routines convert these data to a new map, stored as a computer array, in which each discrete area is approximated by a number of cells of predetermined size and each cell is associated with the appropriate basic legend data in coded form. Figure B2 shows the map in Figure B1 as ouput by the computer



LEGEND

NUMERIC	DESCRIPTION
110	Village
350	Irregular surface
400	Idle land
403	Idle land with channels <50 m in width
503	Cultivated land with channels <25 m in width
780	Gravel or rocky surface with obstacles (lava field)

Figure B1. Manually prepared land-use map



NOTE: Land-use boundaries drawn manually.

LEGEND

ALPHANUMERIC	DESCRIPTION
4F	Village
%L	Irregular surface
+J	Idle land
+M	Idle land with streams < 50 m in width
&I	Cultivated land with streams <50 m in width
JZ and GX	Other land use, gravel or rocky surface with obstacles (lava field)

Figure B2. Land-use maps after digitizing in the computer program

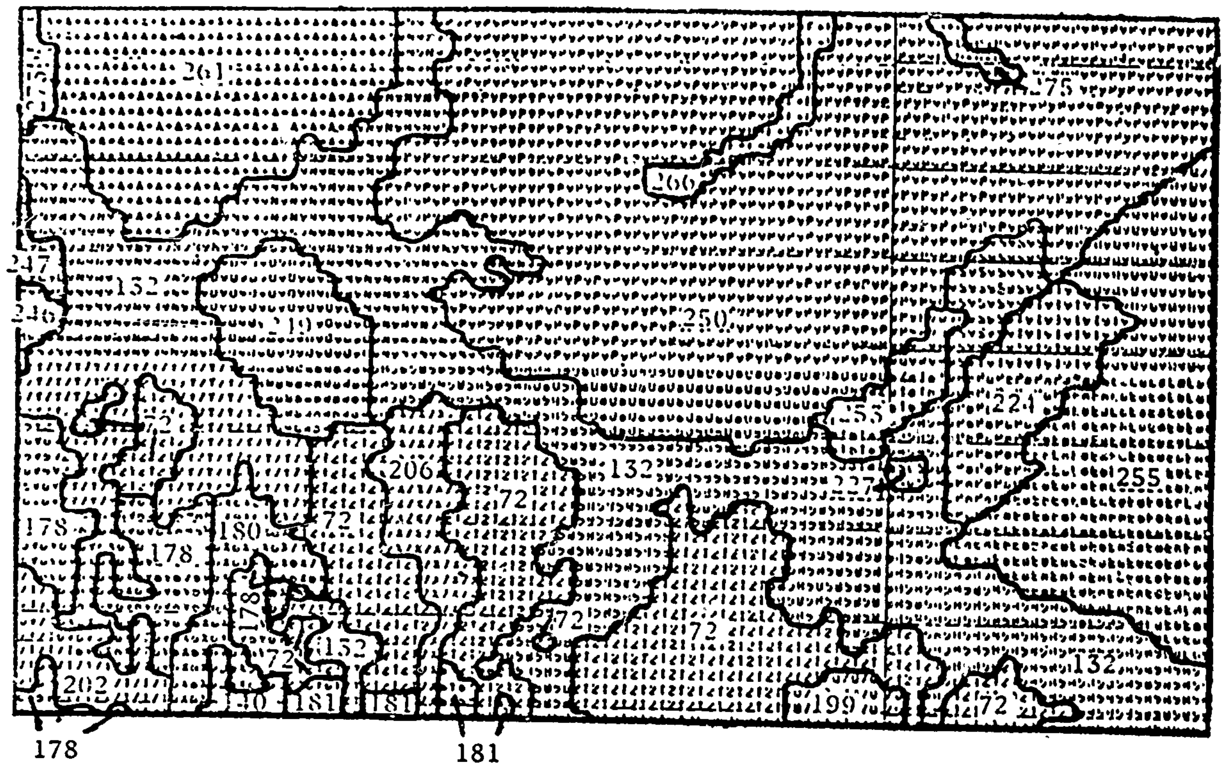
using 105.83 by 127-m cells.

8. Upon completion of the line-follower operation for a given portion of the map, the data tapes are read by an appropriate computer program and replotted on a computer-controlled X-Y plotter for comparison with the original map. Corrections are made at this time by retracing the boundaries as necessary.

9. When the manual overlay data for all individual maps of areal aspects of the terrain are corrected and edited, they are overlaid in the computer (by means of various routines) to produce a final consolidated map and corresponding extended legend. New patches may be defined at this time by the areal intersections of patches from two or more of the overlaid maps. The composite map is stored in two computer arrays, one that identifies each cell with a terrain unit and a second that gives the composite legend information for each terrain unit. Subsequent manipulations to assign terrain factor values are all done with the legend information array only.

10. At this stage of the process, the map consists of a mosaic of small areas (Figure B3) within each of which all descriptors of land use, slope, soil, surface geology, and gross vegetation from the available data are identical. These areas are logical areal terrain units or patches by basic definition, since there are no data upon which to assign anything other than a single set of mobility factor values throughout any one of them.

11. In the next step, the composite qualitative legend information for each patch is interpreted to assign a reasonable, internally consistent set of quantitative terrain factor classes to the patch. This is done by examining appropriate subsets of the qualitative information and inferring from each class values for specific single-terrain factors or sets of values for factor families. Interpretation is based on supporting data and reasonable assumptions about the association of specific mobility factors with the quantitative/qualitative descriptors in the legend, under the influence of prevailing cultural practices and climate. For example, in forested areas, the mobility model requires a stem size and spacing distribution for the vegetation in a terrain unit.



NOTE: Numbers indicate terrain unit numbers.
Terrain unit boundaries are drawn manually.

Figure B3. Final digitized terrain unit map

For the West Germany terrain in the present study, data from many sources, including measurements made by WES several years ago in Germany, were consulted to establish a series of such density curves consistent with the climate and associated with forest type (coniferous, deciduous, mixed), forest management practices (state, nonstate forest), soil type, and the slope of the ground on which the forest lies.

12. Because of the discrete values in the composite legend data, these interpretations can be written as algorithms and formed into a computer routine for consistently translating the coded qualitative legend directly into quantitative terrain factor classes. (Table B2 shows the class intervals used.) Design of the translation routine makes use of many additional data sources (as already noted), including data from air photos of areas of special interest or complexity. Separate routines are used for different geographic areas to reflect appropriate climatic and cultural influences and the kinds and quality of the available basic map data. In recognition of the variability of nature and of the fallibility of the translation algorithms, computed class interval designators are, one time in four, randomly varied by ±1 class (where possible) before final assignment.

Soil strength predictions

13. Of particular criticality to vehicle performance in the hierarchy of terrain factors is the soil strength [cone index (CI) for sand or rating cone index (RCI) for other soils] assigned to a given patch, once the patch is defined by its prevailing slope and the qualitative descriptors from the legend of the source maps. These assignments (one for each of four soil moisture conditions) are based on predictions made with the WES model for predicting soil moisture and strength (SMSP).[18] SMSP uses the soil type classification (according to the Unified Soil Classification System, USCS[19]), the drainage situation in which that soil is found, and the daily rainfall history to predict day-by-day soil moisture content in the soil layers critical to vehicle operation and the resulting soil strength in terms of CI or RCI.

14. In applying SMSP in the present study, long-term rainfall records of a reporting weather station considered representative

Table B2

Areal Terrain Factors, Classes, and Intervals (Except Lake and Marsh Factors)

Terrain Factors	Class Numbers 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Surface Type*	Fine Grained (Other)	Coarse Grained	Muskeg	CH										
Surface strength (CI or RCI) Class range value selected for prediction	281-300	221-280	161-220	101-160	61-100	41-60	33-40	26-32	17-25	11-16	4-10			
Slope (%) Class range value selected for prediction	1-2	3-5	6-10	11-20	21-40	41-60	61-70	70-90						
Obstacle approach angle (deg) Class range value selected for prediction	179	181	176-178	182-184	171-175	185-190	159-170	191-202	149-158	202-211	136-149	212-225	90-135	226-270
Obstacle vertical magnitude (in.) Class range value selected for prediction	3-6	7-10	11-14	15-18	19-24	25-33	33-45							
Obstacle base width (in.) Class range value selected for prediction	48-150	36-47	24-35	12-24	6-12									
Obstacle length (ft) Class range value selected for prediction	1	2-3	4-6	7-10	11-20	21-40	41-100							
Obstacle spacing (ft) Class range value selected for prediction	198	66-197	37-65	26-36	19-25	13-18	9-12	2-8						
Obstacle spacing type	Random	Linear												
Surface roughness x 10 Class range value selected for prediction	1	2-4	5-6	7-8	9-12	13-16	17-22	23-32	33-45					
Stem diameter (in.) Factor value	0	>1	>2.4	>3.9	>5.5	>7.0	>8.7	>9.8						
Stem spacing (ft) Class range value selected for prediction	328	66	53	31	22	16	11	4						
Visibility (ft) Class range value selected for prediction	165-300	79-164	31-78	30-38	20-29	16-19	10-15	6-9	1-5					

* Shallow snow-over-frozen ground is handled as a scenario input.

of each area were consulted. From these records, a single-sample day-by-day rainfall history for a full year was generated for each area, which duplicated the recorded long-term average rainfall statistics for the selected station in terms of yearly average, monthly average, and monthly days with more than or less than specified amounts of rainfall. These synthetic records were used as rainfall inputs for each soil type and each drainage condition recognized by SMSP (Tables B3 and B4) to produce a series of 1-yr-long records of corresponding soil strengths in the 0- to 6-in. layer. Samples of typical records, two for the Mid-East study area and two for the West Germany study area, are shown in Figures B4-B7. The soil type-drainage situation to which each refers is given in terms of codes used in the model as shown in Table B3.

15. To approximate the not uncommon occurrence of especially wet years, a second set of predictions was made for each area by simply increasing daily rainfall in the sample day-by-day record by 50 percent throughout the full year.

16. From these sets of predictions, four soil strength classes were chosen for each soil type-drainage situation. The wet-season soil strength is the mean soil strength during the 30-day period of normal rainfall that results in the least soil strength. Dry-season soil represents the 30-day period in which soil strengths are highest. Average-season soil strength is the mean strength during remaining periods. Finally, a "wet-wet" season soil strength is assigned from the wet-year predictions on the basis of 10 consecutive days during which soil strength is least. In the subsequent translation from the basic available data to mobility-oriented terrain factors, soil type and slope in the patch were used to select the appropriate set of dry, average, wet, and wet-wet soil strength classes.* Each strength in terms of class is later assigned a random value within the class range, as described in the next paragraph.

* Only the dry and wet-wet conditions were played in the basic HIMO Study. To simplify terminology in the remainder of the report, the "wet-wet" seasonal condition is referred to as the wet (study) condition.

Table B3

Surface Composition Groups Considered in SMSP[18]

Material			Organic Content %	Drainage* Potential Class	Group Code
Groups with Similar Material in 0- to 15- and 15- to 30-cm Layers					
Water			0	0	8888
Pavement and structures >25% coverage				2	0101
Rock, stones, boulders, and cobbles, P.D. sizes ≥0.074mm, is ≥50%, and >76.2mm, is >25%				2	0202
Coarse grained P.D. sizes >0.074mm, is ≥50%	Gravel, P.D. sizes >4.76-76.2mm, is >25%	Clean gravel, P.D. sizes <0.074mm, is <5%	>0-7	2	0303
		Gravel with fines, P.D. sizes <0.074mm, is >5-50%		2	0707 or 1111**
	Sand, P.D. sizes >0.074-4.76mm, is >25%	Clean sand, P.D. sizes <0.074mm, is <5%		2	0505
		Sand with fines, P.D. sizes <0.074mm, is ≥5-50%		1	0606
				2	0707
Fine grained, sizes <0.074mm, is >50%	Silt, LL <35 and PI <15			1	0808
				2	0909
	Clay, LL >35 or PI >15			1	1010
				2	1111
Organic silts and clays (plastic)			>7-30	0	1212
				1	1313
Peat (nonplastic)			>30	0	1414
Groups with Different Material in 0- to 15- and 15- to 30-cm Layers					
Sand, 0-15 cm, over Clay, 15-30 cm			>0-7	1	0610
				2	0711
Silt, 0-15 cm, over Clay, 15-30 cm				2	0911

NOTE: PD = Particle diameter
LL = Liquid limit
PI = Plasticity index

*Drainage potential classified by occurrence of water table as follows:

Class 0 Water table occurs at surface 90% or more of the time

Class 1 Water table occurs at the surface less than 90% and above 120-cm depth 10% or more of the time

Class 2 Water table occurs above 120-cm depth less than 10% of the time

** Gravel with sand matrix coded 0707; gravel with clay matrix coded 1111

Table B4

Soil Water, Density, and Strength Surface Composition Groups with Constant Values Considered in SMSP[18]

Material	Group Code	Water Content* percent	Density** g/cm^3	Strength CI
Water	8888	100	1.00	0 (liquid)
Pavements and structures	0101	1	2.50	750+
Rock, stone, cobbles, boulders	0202	1 to 5	2.15	750+
Clean gravel	0303	1	2.00	100
Saturated organic silt-clay	1212	90†	0.80	25
Peat and muck	1414	90†	0.80	25

* Percent on dry-weight basis except for water.

** Dry density except for water.

† Represents an average value estimated from a small number of samples. Water contents are highly variable and increase with an increase in the percent organic matter of the material.

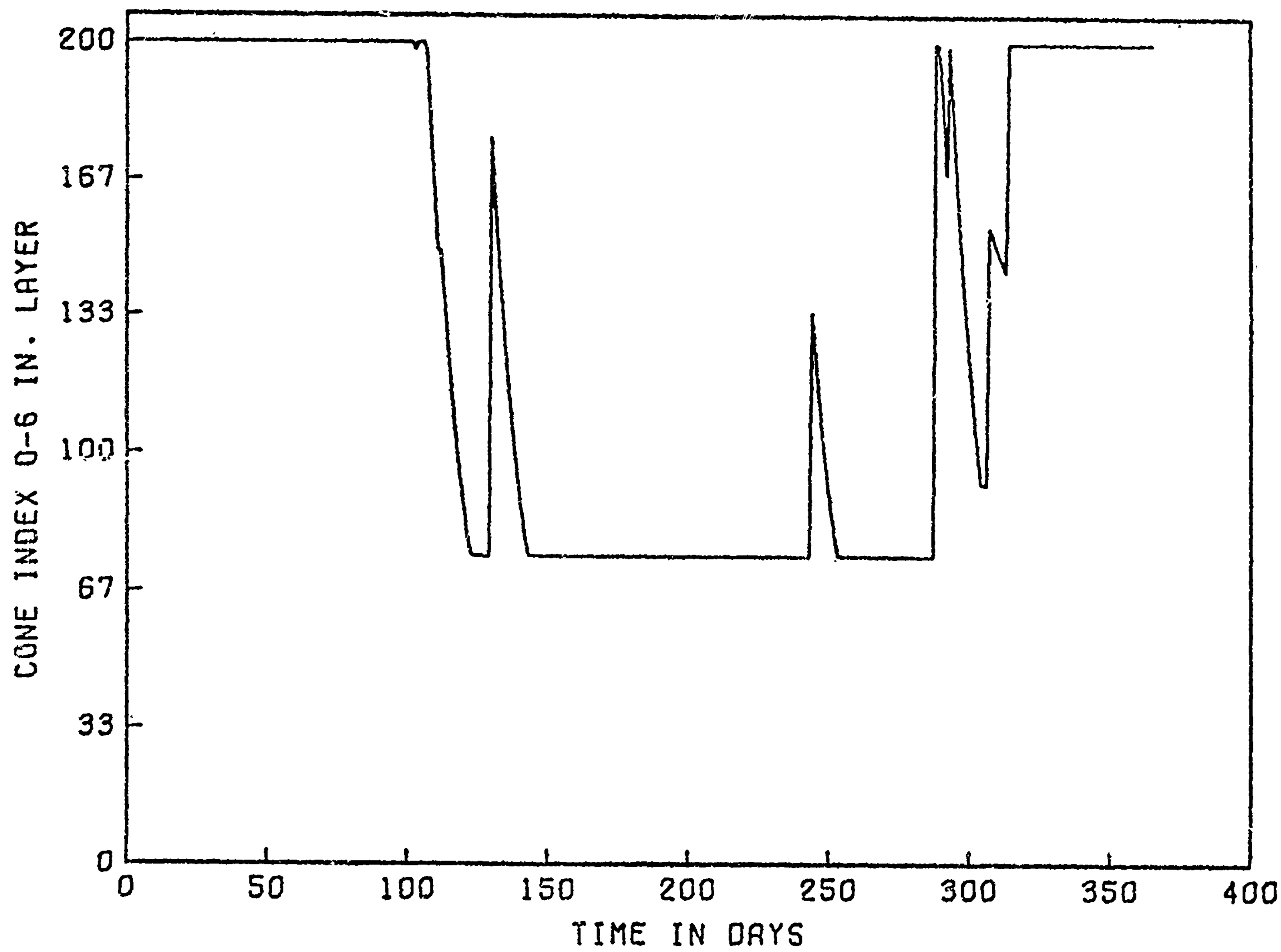


Figure B4. Soil strength as a function of calendar time over a typical year for Mid-East soil group 0505, Drainage potential class 2

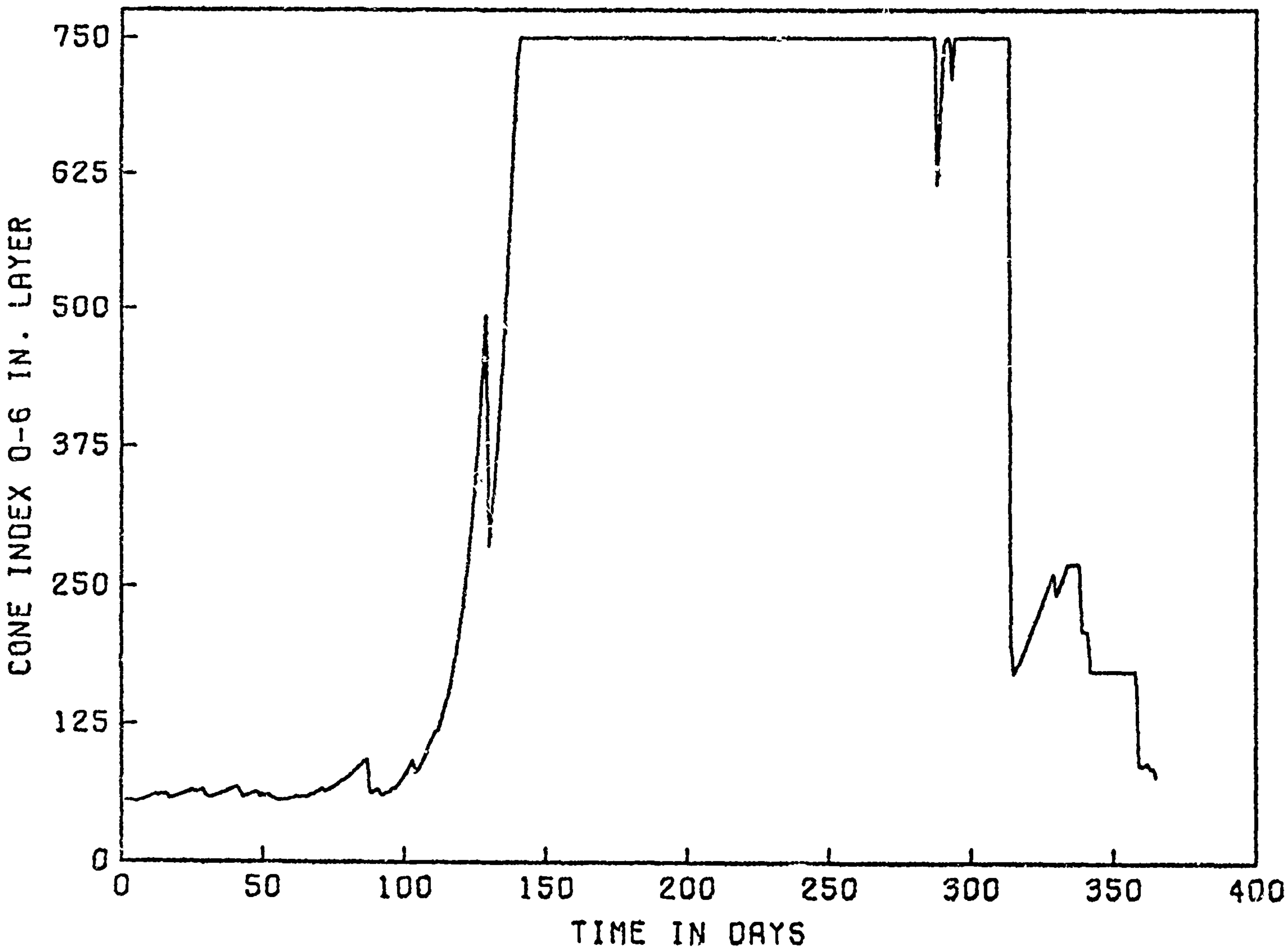


Figure B5. Soil strength as a function of calendar time over a typical year for Mid-East soil group C808, drainage potential class 7

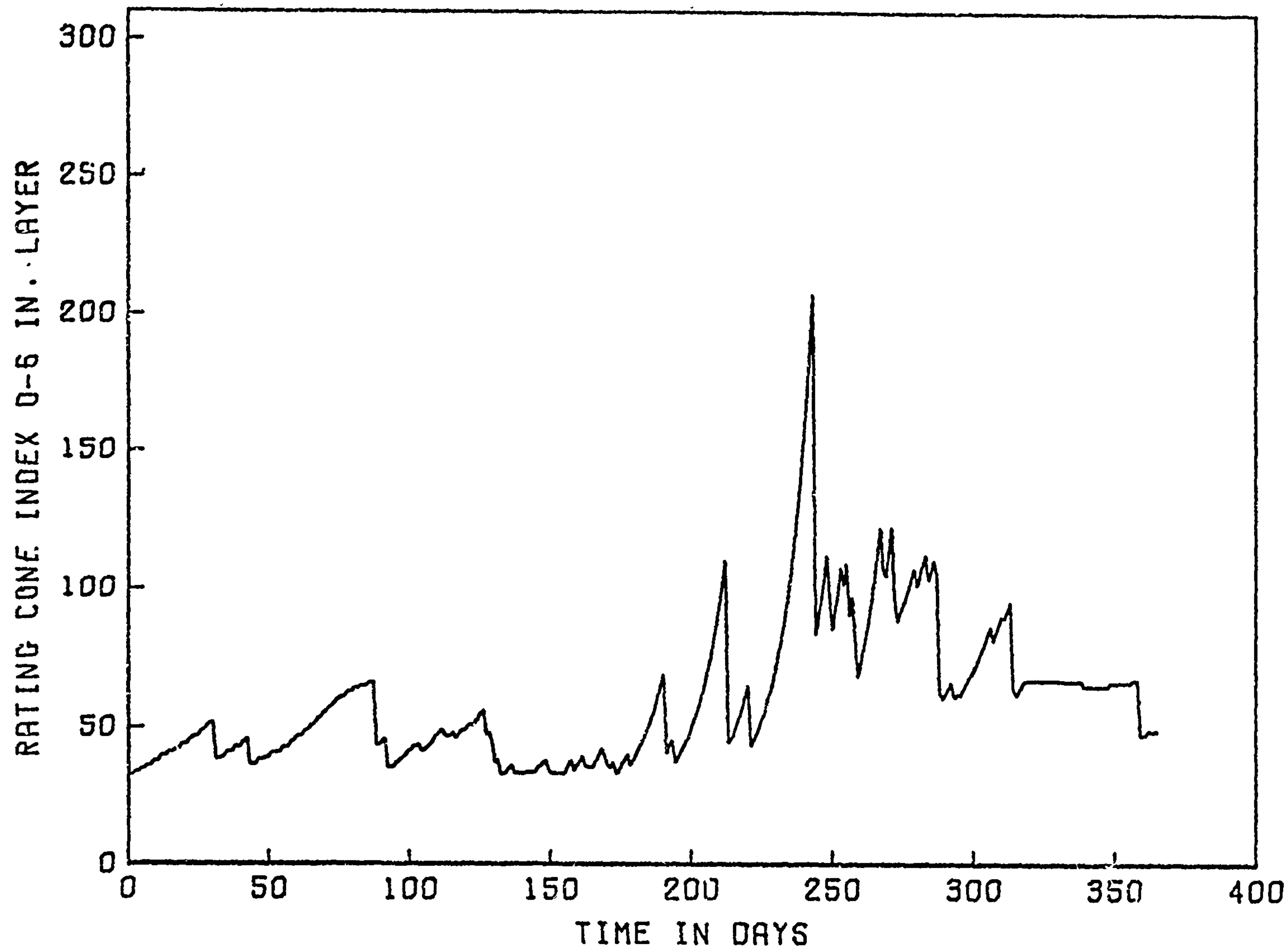


Figure B6. Soil strength as a function of calendar time over a typical year for West Germany soil group 0808, drainage potential class 2

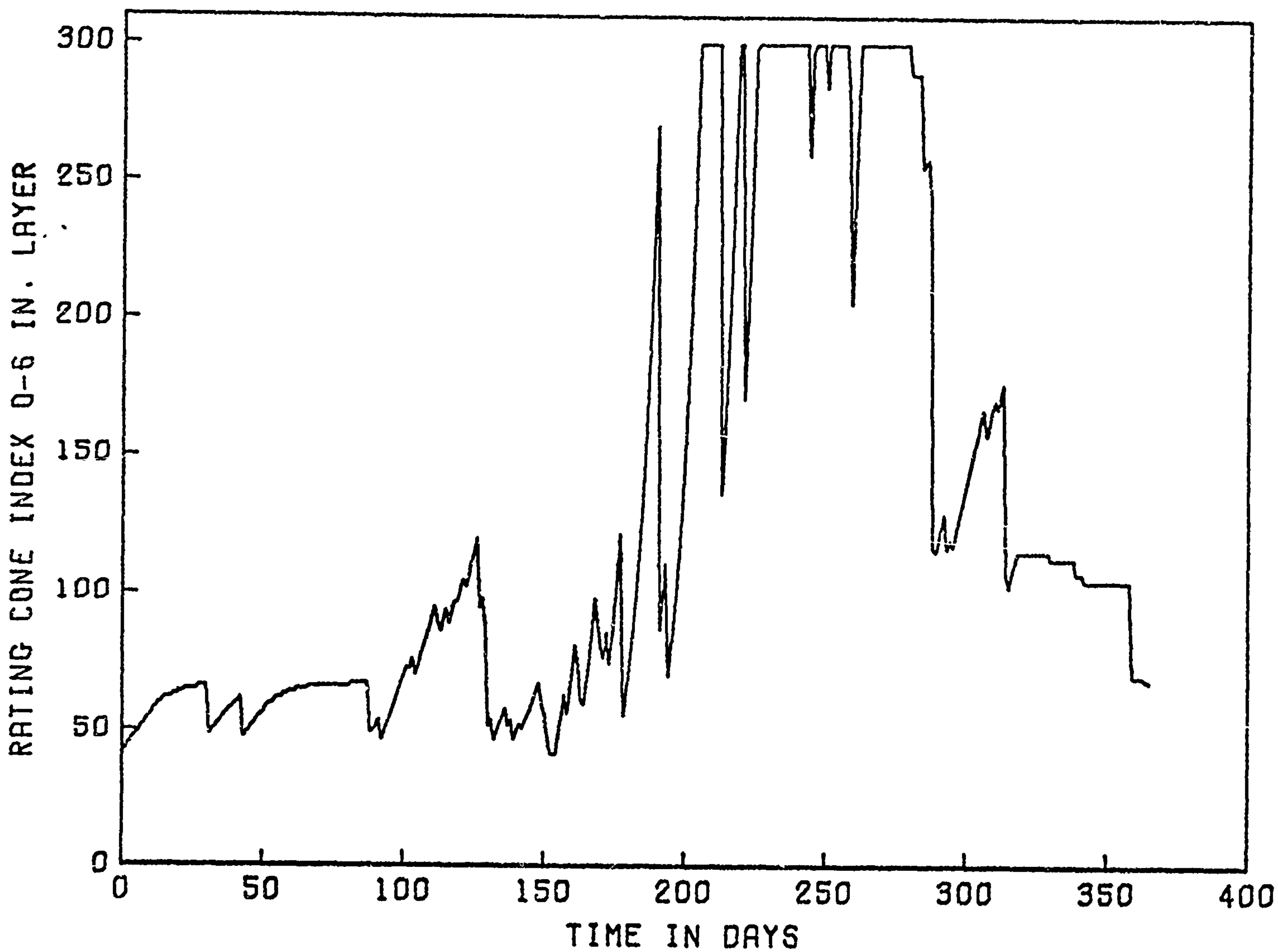


Figure B7. Soil strength as a function of calendar time over a typical year for West Germany soil group 0909, drainage potential class 1

Snow-covered terrain

17. For temperate study area, snow is treated as a temporal factor. When snow is called as a scenario condition (in place of seasonal soil strength condition), values for snow depth, density, apparent cohesion, and angle of internal friction are also presently specified which are then treated as characterizing all off-road and trail terrain units.

Assignment of areal terrain factor values

18. The areal terrain prediction module of AMM uses actual values for the numerous terrain factors rather than class designators. In a final step, numerical values for each factor in a specific patch are assigned random values within each designated class range describing the patch. Thus, two patches that are identical at the factor class interval level are no longer necessarily identical at the factor value level. This final step in assigning terrain factor values to the map is done only once to complete the map legend. When the legend is completed, all vehicles subsequently see each individual patch in terms of an identical array of numerical values for the terrain factors describing it.

19. When the qualitative composite map legend data have been translated and values assigned, the result is a terrain factor complex, or patch, map containing all of the areal terrain data for the mapped area that are needed by AMM. Moreover, the map and all of the data are immediately available in the computer for making vehicle performance predictions, statistical aggregations of performance in the area, performance maps, etc.

APPENDIX C: PREPARATION OF LINK DATA

1. A major step in interfacing AMM with the extensive route information contained in the composite route overlay map for a study area (paragraph 23 of the main text) is the characterization of all parts of that network in terms of areal, linear, and road terrain units and associated distances. This is done link-by-link in a computerized routine that relates the specific path of each link, as input by a manually operated digitizing line-follower, to the mobility terrain data for the area stored in digital form in the computer.

2. The path between the two nodes that identify a link is described twice at this time. First, the path is described "as-is", i.e. in terms of the roads, trails, or cross-country traverses exactly as shown for the link on the composite network overlay map. All bridges are assumed intact and passable, and any fords are negotiable. The second characterization describes the total link as an off-road traverse along the same path, but as though all indicated roads, trails, bridges and fords do not exist. (If a link, as-is, is already wholly off road, the two characterizations are identical.) Conceptually, the off-road link characterization describes the situation within 50 to 100 m each side of the designated road which vehicles, forced off the road for any reason, would encounter in attempting to bypass the on-road barrier by running roughly parallel to the road and generally in sight of it.

3. The first step in developing the link data is to input the entire route network map and the supporting data it contains to the computer. This is done using a manually operated digitizing line-follower, which records on magnetic tape the digitized coordinates of points selected by the operator along the routes on the map. The process begins by entering on the magnetic tape the link identification, which is simply the pair of node numbers connected by the link. Next, the road class at the selected starting end of the link is entered, and then a flag as to whether the first segment of the link runs predomi-

nantly along topographic contours, normal to them, or something between.* The operator then places a cursor on the beginning node of the link and presses a button that records its coordinates. The cursor is moved along the route, and closely spaced coordinates are recorded to describe its direction and curvature.

4. Whenever route type or direction relative to the topographic contours changes or a linear feature is crossed, before proceeding further, appropriate new data are entered at the "division" point where the change or feature occurs.

5. Upon completion of the line-follower operation for a given portion of the network map, the data tapes are read by an appropriate computer program and replotted on a computer-controlled X-Y plotter for comparison with the original map. Corrections are made at this time by retracing the routes as necessary.

6. The corrected and edited magnetic tapes containing the network map are then overlaid in the computer on the similarly digitized mobility terrain maps describing the areal and linear terrain. The computer places additional division points in the link route characterization wherever the path crosses the boundary between two areal terrain units.

7. The digitized coordinates are analyzed at this stage to establish route curvature, and a final set of division points is added to distinguish segments of the route according to path curvature. In recognition that the curvature shown on the 1:50,000 base maps only approximates what is in fact on the ground, road curvature is calculated on the assumption that the change in route direction detected from the digitized coordinates occurs over a maximum distance of 30 m. This interpretation tends to increase and sharpen curvature where shown on the map, in partial compensation for the actual curvature which is lost in the mapping resolution. Resulting curvature is expressed directly in terms of an associated nonvehicle-dependent safe speed limit under dry conditions based upon ASSHO criteria for the road class.[15] Highway

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* The network map, on acetate, is overlaid on the basic topographic map during digitizing, and this determination is made by the digitizer operator as he proceeds.

superelevation is considered only for superhighways, which are assumed in all cases to be banked to allow a safe speed of 70 mph under normal, dry road conditions.

8. The final step at this stage of the processing is to compute to the nearest 0.01 mile the distance between adjacent division points for all link segments and the total link distance. At this point link is described in terms of a series of segments for each of which the following information is known:

- a. Segment length.
- b. Route type.
- c. Route direction relative to prevailing topographic contours.
- d. Curvature (safe speed in dry road conditions).
- e. Areal terrain unit number throughout the segment.

9. Division points associated with potential linear feature crossings are overlaid in the computer on the stored map of linear feature terrain units, and the linear feature terrain unit number for each is recorded. The program at this time searches the major linear feature terrain unit data 100 m along the route in each direction (to protect against errors due to possible misregister of the route network and linear feature maps). If it finds a major feature, that feature's terrain unit number is entered in the link specification. If it fails to find a major feature, a minor feature terrain unit number characteristic of the local area, obtained from the areal-linear feature data (Appendix B) is entered.

10. The link as an off-road traverse is now fully described. Segment lengths identified with a common areal terrain unit are accumulated, the number of crossings of each unique linear terrain unit* is counted, and both sets of number pairs are recorded. Sequence and travel direction data, available at this stage, are deliberately sacrificed in order to keep computer storage requirements for the large areas involved in reasonable bounds (Appendix A, paragraph 46).

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* Linear feature crossings at different locations (especially smaller features) may have essentially the same cross section, soils, and hydrologic characteristics and are then identified by a common linear terrain unit number.

11. To describe the road and trail segments of a link for the as-is description, the data listed in paragraph 8 are interpreted according to the class of road specified (superhighway, primary, secondary, or trail). From these data, road or trail surface type and strength, slope, surface roughness, and (for trails only) roadside visibility are assigned. (Curvature is already computed.) Reflecting the relative uniformity of roads, road factor values are assigned only in terms of class intervals. (The midrange value for the designated class for each factor is subsequently used to make all on-road speed predictions in AMM.)

12. Surface type is taken directly from road type. All road types except trails are taken to be all-weather roads. Superhighways and primary roads are by definition paved and are assigned a coefficient of maximum traction when dry of 70 percent. Secondary roads are assumed to be paved or high-quality gravel roads with a coefficient of maximum traction in either case of 60 percent when dry. Trails are considered to be of the same soil type as the surrounding areal terrain with the soil strength in the same class interval.*

13. Slope class is assigned based upon the slope of the surrounding areal terrain and the direction of the route relative to the topographic contours. When the route segment is designated as generally following the countours, slope class 1** is assigned to superhighways and

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* It is recognized that trails will generally be stronger than the parent soils along side them. Trails in military use, however, are subject to repetitive traffic. WES research has shown that the soil strength required to support 50 passes by a vehicle is 2.2-2.4 times that required for a single pass.[22] Use of the parent soil strength on the trails, along with the first-pass soil performance prediction algorithms (as was done in making the on-trail prediction for the HIMO study), thus in effect approximates 50-pass traffic on trail soils having twice the strength of the parent soils, while avoiding the bookkeeping required to make a more detailed assessment.

**

Slope class	1	2	3	4	5
Slope range, %	<2	<5	<10	<20	<50
Value used in making predictions, %					

primary roads; class 1 or 2 (randomly selected) to secondary roads; and class 1, 2, or 3 (again randomly selected) to trails. In neither of the latter two cases is the assigned value before being classed greater than one-half the prevailing areal slope.

14. When the route segment is designated as running generally normal to the contours, the slope class assigned is that of the prevailing areal slope but not greater than 5 percent (class 2) for superhighways, 10 percent (class 3) for primary roads, 20 percent (class 4) for secondary roads, and 40 percent (class 5) for trails. When the route segment is flagged as running intermediate to the first two cases, the assigned slope is one-half the areal slope, subject to the same class maxima.

15. Surface roughness of superhighways is assigned as class 1.* Primary roads are randomly assigned roughness classes 1, 2, or 3; secondary roads, 2, 3, or 4; and trails, class values 3 through 8.

16. Roadside recognition distance due to vegetation, assigned only for trails, is taken to be identical with that of the areal terrain unit associated with the route segment.

17. A sample printout from the completed link data file is shown in Figure C1. The Mid-East study area network required such specifications for 854 links; the West Germany study area, for 2184.

18. The program generates three supporting files. The first is a listing of the areal terrain units actually encountered in the total area network (15 percent of some 4300 units in the complete Mid-East study area; 31 percent of 12,400 in the West Germany area), along with the complete specifications for each (Figure C2). The second and third files compile similar lists for road units (Figure C3) and linear terrain units describing required linear feature crossings (Figure C4). These three files are used by AMM to make the vehicle speed and linear-feature-crossing-time predictions required for the job travel times developed in the study.

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* Roughness class	1	2	3	4	5	6	7	8	9
Elevation (rms), in.	<0.1	<0.4	<0.6	<0.8	<1.2	<1.6	<2.2	<3.2	<4.5

1263	6849	6	2							
10001	10	10002	2	10003	1					
37	13									
1263	3249	2	2							
10001	10									
37	10									
1298	3249	6	4							
10001	2	37	42	20001	2					
37	44	20001	2							
2419	3249	6	6							
52	72	35	28	37	38					
52	72	35	28	37	38					
1298	1498	30	22							
10004	7	10005	1	10006	56	10007	0	10008	4	10009
150	11	175	92	228	4	20002	6	20003	1	
37	28	98	33	124	88	181	13	150	11	175
20003	1									
1498	4339	6	4							

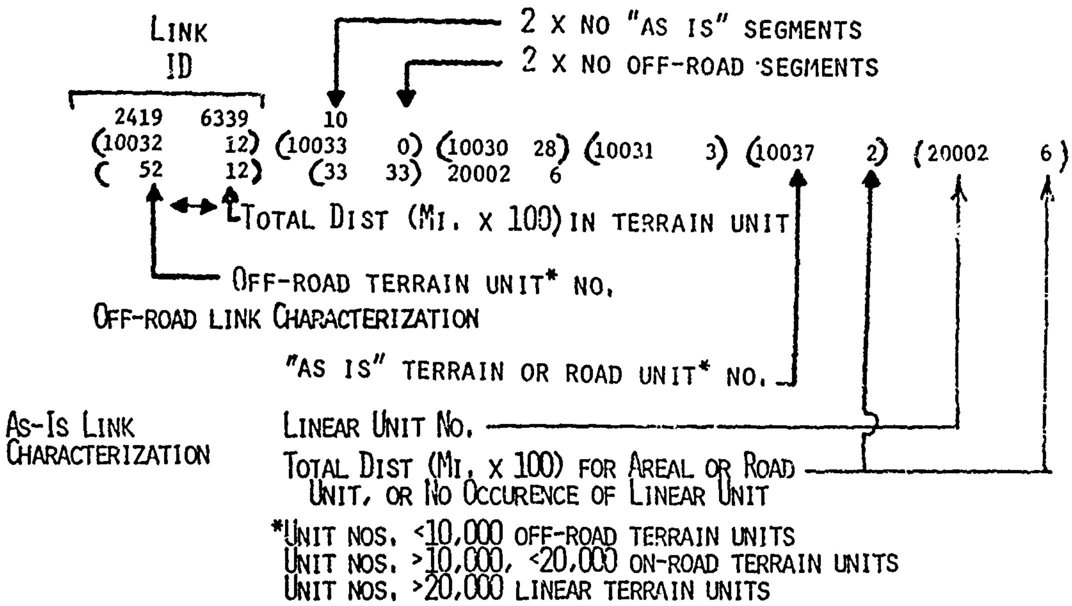

Figure C1. Partial link data file

Terrain Unit No.	Special Classed Terrain Information										Urban Code	Seasonal Soil Strengths (CI/RCI)				Grade, %	Obstacle, roughness, vegetation, visibility values used by Army Mobility Model, and total in-unit distance. (Values per terrain unit) (See Appendix A)				
37	2	1	1	4	4	2	4	4	4	4	4	300	299	124	107	4	204	28	45	83	47
52	2	1	1	4	4	3	4	4	4	4	4	282	282	137	128	10	211	29	38	66	
35	2	1	1	4	4	4	4	4	4	4	4	296	292	136	131	17	205	5	26	51	
98	2	1	1	4	4	1	2	1	1	2	4	283	283	119	117	2	144	12	33		
124	2	1	1	4	4	1	2	1	1	2	4	283	283	119	117	2	144	12	33		
181	2	1	1	4	4	2	5	5	5	5	4	283	282	146	114	3	138	13	30	3	
150	1	1	1	1	1	1	1	1	1	1	1	295	283	283	283	2	179	6	687	1	
175	2	1	1	4	4	1	4	1	1	2	4	281	281	148	143	2	106	11	31	3	112
228	2	1	1	4	4	1	4	1	1	2	4	287	283	139	123	2	189	10	23	62	137
170	2	1	1	4	4	1	2	2	2	2	4	288	285	137	123	2	194	26	44	70	30
246	2	1	1	4	4	1	4	1	1	2	4	284	281	141	114	1	191	24	37	47	
214	2	1	1	4	4	2	2	2	2	2	4	292	282	145	145	5	198	8	45	69	
33	2	1	1	4	4	2	3	3	3	3	4	297	292	104	102	4	142	25	63		
206	2	1	1	4	4	1	2	1	1	2	4	292	291	131	102	1	188	4	21		
216	2	1	1	4	4	1	2	2	2	2	4	290	287	123	121	1	105	17			
149	1	1	1	1	1	1	1	1	1	1	1	297	282	282	282	2	179				
97	2	1	1	4	4	4	3	3	3	3	4	285	281	155	136	11	113				
148	2	1	1	4	4	4	6	6	6	6	4	288	282	145	139	17	133	22			
111	2	1	1	4	4	4	5	5	5	5	4	285	283	116	113	15	187	3			
63	2	1	1	4	4	2	2	1	1	2	4	290	284	160	134	4	210	17	43		
34	2	1	1	4	4	2	4	4	4	4	4	291	291	140	129	3	105	21	32		
84	2	1	1	4	4	4	4	1	1	2	[illegible]	288	283	117	102	19	130	16	28	72	
51	2	1	1	4	4	2	4	1	1	2	[illegible]	294	286	109	108	4	209	4	27	71	
191	2	1	1	4	4	4	4	4	4	4	4	283	282	146	131	18	201	7	25		
156	2	1	1	4	4	3	2	2	2	2	4	297	290	119	104	8	121	44			
139	2	1	1	4	4	4	2	2	2	2	4	296	283	109	106	13	205				

Figure C2. Partial listing of areal terrain units found in a route network

Assigned Road Unit No.	Road Class	Urban Code	Soil Type	Seasonal Soil Strength*				Slope	Seasonal Roadside Visibility*				Roughness	Curve Speed (Mph)	Distance (Mi x 100)
10001	4	4	2	1	1	4	4	4	4	3	3	4	5	50	43
10002	4	4	2	1	1	4	4	4	4	3	3	4	4	28	17
10003	4	4	2	1	1	4	4	4	4	3	3	4	4	40	16
10004	3	4	2					1					2	60	165
10005	3	4	2					1					3	10	42
10006	3	4	2					1					3	60	63
10007	3	4	2					1					2	10	31
10008	3	4	2					1					4	36	41
10009	3	1													59
10010	3	4	2					1					2	32	265
10011	3	4	2					1					2	48	43
10012	2	4	2					1					1	36	98
10013	2	3						1					2	23	69
10014	4	1	2	1	1	4	4	1	4	2	2	2	3	50	9
10015	4	4	2	1	1	4	4	1	4	2	2	2	4	18	6
10016	4	4	2	1	1	4	4	1	4	2	2	2	3	50	44
10017	4	4	2	1	1	4	4	1	4	2	2	2	3	18	49
10018	4	4	2	1	1	4	4	1	4	2	2	2	6	14	9
10019	4	4	2	1	1	4	4	1	4	2	2	2	5	40	74
10020	4	1													9
10021	3	4	2					3					2	60	109
10022	3	2													90
10023	3	4	2					3					3	23	53
10024	3	4	2					3					4	36	10
10025	3	4	2					3					3	26	27
10026	3	4	2					1					2	32	39

* Used for performance prediction on trails (road class 4) only.

Figure C3. Partial listing of road units found in a route network

Assigned ID No.	Cross-Section ID No.	Feature Type	Bank Soil Type	Seasonal Bank Soil Strengths				Local Slope	Occurrences
20001	1	1	2	1	1	4	4	2	2
20002	1	1	2	1	1	4	4	1	2
20003	10	1	2	1	1	4	4	1	4
20004	1	3	2	1	1	4	4	1	6
20005	1	1	2	1	1	4	4	3	2
20006	12	1	2	1	1	4	4	2	2
20007	1	1	2	1	1	4	4	4	6
20008	1	1	1	1	1	1	1	1	1
20009	4	1	2	1	1	4	4	2	4
20010	6	1	2	1	1	4	4	2	8
20011	6	1	2	1	1	4	4	3	4
20012	9	1	2	1	1	4	4	4	7

Figure C4. Partial Listing of Linear Feature Crossing Terrain Units Found in a Route Network.

19. Total network distance in each individual areal and road terrain unit and the total number of crossings of each linear terrain unit are accumulated. With this further information, the three terrain unit lists above constitute a sample of the entire area from which various area-oriented statistics can be later calculated. Spot-check comparisons over single-map sheets of average speeds on the corresponding route network as an off-road traverse with average speeds in the full off-road area indicate that the traverses are essentially unbiased samples.

APPENDIX D: STATISTICAL EXAMINATIONS OF INDIVIDUAL VEHICLE PERFORMANCE IN THE TWO HIMO STUDY AREAS

1. In the following sections several statistics on measures of individual vehicle performance in the two HIMO study areas are summarized and discussed in some detail. Data in this appendix are used in the main report to propose an overall appraisal of the study vehicles in relation to levels of tactical mobility performance defined in the 1972 DA WHEELS Study.[1]

The Composite Route Network As A Terrain Sample

2. The link time predictions were aggregated for each vehicle and situation by considering that the vehicle travels once over each link. Table D1 summarizes the major characteristics of the two composite route networks of which the links are components.

3. When the as-is link predictions are examined, the composite route network becomes a sample of all roads and trails in the area, plus such off-road traverses as might be required for mission completion under reasonably favorable combat conditions (18.1 percent off road in the Mid-East study area; 0.1 percent, in the West Germany study area). Statistics developed on this basis indicate the compatibility of a vehicle with all missions that might be called for (with no route disruption), irrespective of their likelihood or frequency in relation to that vehicle.

4. When all links are treated as off-road traverses (Appendix C, paragraph 2), the route network becomes a substantial scenario-oriented sample of all off-road areal and linear terrain throughout the study area. Vehicle performance statistics from this data base indicate the off-road performance potential of a vehicle throughout the area covered by the scenario play as a whole.

5. Table D2 illustrates a small part of the output of the computer routine developed to assemble the vehicle performance data from the link predictions. Tables D3-D9 are extracts from the complete printouts.

Table D1

Characteristics of Composite Route Networks

Study Area Features	Mid-East	West Germany
Total distance, mi	533	1678
Number of links*	854	2184
Average link length, mi	0.62	0.77
Composition of as is** Network, percent		
Superhighways	0	3.1
Primary roads	7.3	21.1
Secondary roads	29.7	61.4
Tertiary roads and trails	44.9	14.3
Off-road traverses	18.1	0.1
	100.0	100.0

* See paragraph 7, main text.
** See paragraph 28, main text.

Table D2
Sample Link Statistics Output
(All Vehicles, One Condition, Route As-Is and Off-Road)

VEH #	AVG TIME	AVG SPEED	LINEAR FEATURES-ALL #	%	MEAN X-T	SD	% T-X	%TOT T-X	LINEAR FEATURES>10 #	%	MEAN X-T	SD	% T-X	NO-GO #	%	% DIST	% TIME	%TOT DIST	%TOT TIME	TOT GO-T
	ROUTE ASIS			CONDITION WET			2134 SAMPLES			1677.5 Miles										
1	2.5	18.4	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	14	0.6	15.1	86.4	0.2	12.4	4782.1
2	2.4	18.9	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	14	0.6	15.1	88.7	0.2	12.7	4657.1
3	6.6	6.9	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	154	7.1	37.0	94.1	3.2	58.0	6086.4
4	6.7	6.9	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	154	7.1	37.0	94.0	3.2	57.4	6229.1
5	6.7	6.9	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	154	7.1	37.0	93.9	3.2	57.4	6237.2
6	3.4	13.6	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	47	2.2	21.8	92.4	0.7	33.3	4921.1
7	2.3	19.9	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	14	0.6	15.1	88.7	0.2	13.4	4367.6
8	2.9	16.1	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	23	1.1	18.0	89.5	0.3	18.2	5099.0
9	2.4	19.4	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	17	0.8	14.0	88.6	0.2	14.7	4424.5
10	2.4	19.4	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	17	0.8	14.0	88.6	0.2	14.7	4424.5
11	2.9	16.1	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	28	1.3	18.0	89.0	0.4	22.0	4860.6
12	2.7	16.8	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	17	0.8	14.0	84.1	0.2	12.8	5213.2
13	6.0	7.6	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	154	7.1	37.0	95.4	3.2	63.8	4761.3
14	6.1	7.6	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	154	7.1	37.0	95.4	3.2	63.2	4883.8
15	7.0	6.6	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	173	7.9	38.3	94.9	3.7	62.2	5742.6
16	2.7	17.1	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	10	0.5	17.9	87.8	0.2	8.5	5373.5
17	3.3	13.9	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	38	1.7	23.6	93.1	0.6	29.3	5120.6

VEH #	AVG TIME	AVG SPEED	LINEAR FEATURES-ALL #	%	MEAN X-T	SD	% T-X	%TOT T-X	LINEAR FEATURES>10 #	%	MEAN X-T	SD	% T-X	NO-GO #	%	% DIST	% TIME	%TOT DIST	%TOT TIME	TOT GO-T
	ROUTE OFFRD			CONDITION WET			2184 SAMPLES			1677.5 MILES										
1	25.6	1.8	766	35.1	33.2	19.9	60.0	45.4	752	34.4	33.8	19.6	60.3	448	20.5	19.7	69.0	6.5	40.8	7682.7
2	25.2	1.8	766	35.1	35.4	19.7	63.1	49.3	752	34.4	36.0	19.4	63.4	385	-17.6	17.7	66.5	5.2	35.8	8163.1
3	33.9	1.4	760	34.8	35.8	19.0	54.3	36.8	748	34.2	36.4	18.6	54.8	612	28.0	41.6	69.5	16.9	44.9	13532.1
4	34.0	1.4	760	34.8	35.8	18.8	54.1	36.7	748	34.2	36.3	18.5	54.6	603	27.6	41.4	69.2	16.6	44.2	14168.6
5	33.9	1.4	760	34.8	35.8	18.8	54.1	36.7	748	34.2	36.3	18.5	54.5	608	27.8	41.1	69.2	16.7	44.5	13942.9
6	27.6	1.7	766	35.1	20.1	22.6	39.5	25.6	340	15.6	39.4	21.8	56.5	682	31.2	22.7	77.8	10.6	59.3	9120.8
7	34.9	1.3	760	34.8	46.2	20.1	62.6	46.1	746	34.2	47.1	19.3	62.9	672	30.8	23.3	65.9	10.6	45.4	6436.2
8	23.3	1.6	766	35.1	36.6	20.6	60.5	45.4	753	34.5	37.2	20.2	60.7	487	22.3	21.3	67.5	7.4	40.2	8896.7
9	25.7	1.8	766	35.1	36.1	20.2	63.3	49.3	753	34.5	36.6	19.8	63.6	396	18.1	18.9	66.9	5.6	36.0	8252.9
10	25.7	1.8	766	35.1	36.1	20.2	63.3	49.3	753	34.5	36.6	19.8	63.6	396	18.1	18.9	66.9	5.6	36.0	8252.9
11	28.1	1.6	760	34.8	37.0	20.1	60.8	45.8	748	34.2	37.6	19.7	61.1	441	20.2	20.3	65.8	6.6	36.7	10730.4
12	26.3	1.8	760	34.8	34.2	19.3	59.8	45.2	748	34.2	34.7	19.0	60.0	390	17.9	18.0	65.6	5.3	34.6	11609.1
13	35.9	1.3	760	34.8	38.0	19.3	53.8	36.8	749	34.3	38.6	18.9	54.2	746	34.2	38.6	70.3	18.8	51.6	9101.9
14	35.5	1.3	760	34.8	39.4	22.7	55.8	38.6	701	32.1	42.7	20.5	57.8	698	32.0	34.7	68.7	16.0	48.3	10182.7
15	40.9	1.1	760	34.8	44.6	19.9	56.2	37.9	748	34.2	45.3	19.3	56.6	810	37.1	40.1	67.7	21.2	49.5	11205.6
16	26.3	1.7	766	35.1	46.6	20.0	74.4	62.1	754	34.5	47.4	19.3	74.6	264	12.1	16.1	59.4	3.3	23.0	8577.8
17	22.8	2.0	760	34.8	24.9	25.4	53.9	38.0	369	16.9	48.1	16.5	69.8	385	17.6	20.7	72.9	5.8	39.7	11092.3

Table D3

Characteristics of Link Travel Speeds of All Vehicles

Condition	Route	Range Hi mph	Range Lo mph	Range Hi/Lo	V_{mean} mph	δ/V_{mean}	$V_{off}/V_{as\ is}$	V_{cond}/V_{dry}
				Mid-East				
Dry	As is	14.4	4.3	3.4	8.4	0.29	-	-
	Off road	7.5	1.5	5.0	3.2	0.46	0.38	-
Wet	As is	9.5	4.2	2.3	7.2	0.20	-	0.86
	Off road	4.1	1.4	2,9	2.7	0.28	0.38	0.84
Sand	As is	13.7	1.7	8.1	3.9	0,79	-	0.46
	Off road	6.1	0.7	8.7	1.4	0.96	0.36	0.44
				West Germany				
Dry	As is	24.5	16.0	1.5	20.8	0.14	-	-
	Off road	3.5	1.5	2.3	2.4	0.17	0.12	-
Wet	As is	19.9	6.6	3.0	13.6	0.39	-	0.65
	Off road	2.0	1.1	1.8	1.6	0.16	0.12	0.67
Snow	As is	19.3	1.9	10.2	12.4	0.35	-	0.60
	Off road	2.6	0.8	3.2	1.7	0.20	0.14	0.71

Table D4

Average Speed (mph) Over All Links

Mid-East

Vehicle	Route As Is: Dry	Route As Is: Wet	Route As Is: Sand	Route As Is: All Surface Conditions	Off Road: Dry	Off Road: Wet	Off Road: Sand	Off Road: All Surface Conditions
M561	5.7	5.5	3.3	4.5	2.0	1.9	0.9	1.4
M656	8.8	8.6	3.1	5.4	3.0	3.0	0.9	1.7
M520E1	8.3	7.8	5.0	6.7	3.6	3.5	1.7	2.6
M559	8.2	7.7	4.9	6.6	3.6	3.4	1.7	2.6
M553	8.2	7.7	4.9	6.6	3.6	3.4	1.7	2.6
M548E1	9.3	7.8	8.9	8.6	3.4	2.8	3.1	3.1
M151A2	5.2	4.5	2.7	3.8	1.6	1.4	0.7	1.1
M715E1	4.3	4.2	2.7	3.6	1.5	1.5	0.8	1.2
M35A2	8.0	7.5	2.5	4.6	2.5	2.4	0.7	1.3
M49A2C	8.0	7.5	2.5	4.6	2.5	2.4	0.7	1.3
M813	8.8	7.2	2.5	4.6	2.9	2.3	0.7	1.4
M821	8.5	8.0	2.3	4.4	2.9	2.8	0.7	1.4
M816	7.4	6.8	2.5	4.4	2.3	2.2	0.8	1.4
M125E1	8.9	8.5	2.5	4.8	3.5	3.4	0.7	1.5
M818-M127A1C	7.8	5.4	1.7	3.3	2.9*	2.2*	0.7*	1.4*
TDW901	12.7	9.5	4.9	7.7	5.9	4.1	1.6	2.9
M60A2	14.4	7.8	13.7	11.1	7.5	3.0	6.1	4.8

NOTE: 854 links - average link distance 0.62 miles.

* Values suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D5

Average Speed (mph) Over All Links
West Germany

Vehicle	Route As Is Dry	Route As Is Wet	Route As Is Snow	Route As Is All Conditions	Off Road Dry	Off Road Wet	Off Road Snow	Off Road All Conditions
M561	22.0	18.4	16.3	18.6	2.2	1.8	1.8	1.9
M656	22.8	18.9	16.6	19.1	2.3	1.8	1.9	2.0
M520E1	16.3	6.9	12.1	10.4	2.6	1.4	1.9	1.8
M559	16.0	6.9	11.7	10.2	2.7	1.4	1.9	1.9
M553	16.0	6.9	11.7	10.2	2.6	1.4	1.9	1.8
M548E1	21.6	13.6	19.3	17.5	2.1	1.7	1.9	1.9
M151A2	24.2	19.9	15.3	19.1	1.5	1.3	1.3	1.4
M715E1	20.6	16.1	12.6	15.8	2.0	1.6	1.6	1.7
M35A2	24.5	19.4	11.1	16.4	2.3	1.8	1.7	1.9
M49A2C	24.5	19.4	11.1	16.4	2.3	1.8	1.7	1.9
M813	23.3	16.1	9.8	14.5	2.3	1.6	1.7	1.8
M821	21.4	16.8	8.7	13.6	2.3	1.8	1.7	1.9
M816	21.4	7.6	8.2	10.0	2.3	1.3	1.6	1.6
M125E1	20.7	7.6	10.1	10.8	2.5	1.3	1.7	1.7
M818-M127A1C	17.4	6.6	1.9	4.1	2.1*	1.1*	0.8*	1.1*
TDW901	20.0	17.1	15.5	17.3	2.7	1.7	1.8	2.0
M60A2	20.9	13.9	19.3	17.5	3.5	2.0	2.6	2.6

NOTE: 2184 links - average link distance 0.77 miles.
* Values suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D6

Percentages of Network Distance that are NOGO

Mid-East

Vehicle	Route As-Is: Dry	Route As-Is: Wet	Route As-Is: Sand	Route As-Is: All Surface Conditions	Off-Road: Dry	Off-Road: Wet	Off-Road: Sand	Off-Road: All Surface Conditions
M561	3.3	3.3	8.0	4.9	14.4	14.5	43.6	24.2
M656	1.6	1.6	8.9	3.0	9.1	9.1	46.9	21.7
M520E1	0.6	0.6	2.9	1.4	3.6	3.6	15.5	7.6
M559	0.6	0.6	2.9	1.4	3.6	3.6	15.3	7.5
M553	0.6	0.6	2.9	1.4	3.6	3.6	15.3	7.5
M548E1	1.4	1.6	1.4	1.5	7.7	9.4	7.8	8.3
M151A2	3.5	3.5	11.6	6.2	18.5	17.9	60.0	32.1
M715E1	5.0	5.0	10.6	6.9	20.1	20.1	52.6	30.9
M35A2	1.8	1.8	12.7	5.4	10.6	10.7	66.2	29.2
M49A2C	1.8	1.8	12.7	5.4	10.6	10.7	66.2	29.2
M813	1.4	1.8	12.0	5.1	7.5	9.6	60.3	25.8
M821	1.7	1.7	15.1	6.2	8.1	8.5	79.1	31.9
M816	1.7	1.8	9.6	4.4	9.8	10.3	50.9	23.7
M121E1	1.3	1.3	13.2	5.3	6.2	6.4	69.3	27.3
M818-M127A1C *	1.2	2.6	20.3	8.0	6.8*	10.0*	74.5*	30.4*
TDW901	0.7	0.8	4.0	1.8	3.4	3.4	20.6	9.1
M60A2	0.5	2.3	0.5	1.1	1.9	8.7	2.0	4.2

NOTE: 884 links - average link distance 0.62 miles.

* Values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D7

Percentages of Network Distance that are NOGO

West Germany

Vehicle	Route As-Is Dry	Route As-Is Wet	Route As-Is Snow	Route As-Is All Conditions	Off-Road Dry	Off-Road Wet	Off-Road Snow	Off-Road All Conditions
M561	0	0.2	0.1	0.1	5.5	6.5	6.6	6.2
M656	0	0.2	0.1	0.1	4.4	5.2	5.1	4.9
M520E1	0	3.2	0.1	1.1	1.6	16.9	2.9	7.1
M559	0	3.2	0.1	1.1	1.4	16.6	2.7	.6.9
M553	0	3.2	0.1	1.1	1.5	16.7	2.7	7.0
M548E1	0	0.7	0.0	0.2	7.8	10.6	8.0	8.8
M151A2	0	0.2	0.3	0.2	12.1	10.6	10.9	11.2
M715E1	0	0.3	0.3	0.2	5.5	7.4	7.0	6:6
M35A2	0	0.2	0.4	0.2	4.5	5.6	5.9	5.3
M49A2C	0	0.2	0.4	0.2	4.5	5.6	5.9	5.3
M813	0	0.4	0.3	0.2	4.2	6.6	6.0	5.6
M821	0	0.2	0.3	0.2	4.5	5.3	5.7	5.2
M816	0	3.2	0.3	1.2	4.8	18.8	6.1	9.9
M125E1	0	3.2	0.3	1.2	3.3	16.0	5.0	8.1
M818-M127A1C	1.0	3.7	15.1	6.6	4.3*	21.2*	43.4*	23.0*
TDW901	0	0.2	0	0.1	2.3	3.3	2.9	2.8
M60A2	0	0.6	0	0.2	2.3	5.8	2.7	3.6

NOTE: 2184 links - average link distance 0.77 miles.

* Values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D8

Percentages of Links Involving Linear Feature-Crossing Times of More Than 10 Min

Mid-East

Vehicle	Route As-Is				Off-Road			
	Dry	Wet	Sand	All Surface Conditions	Dry	Wet	Sand	All Surface Conditions
M561	0	0.2	0	0.1	0	0.8	0	0.3
M656	0	0	0	0	0	0	0	0
M520E1	0	0	0	0	0	0	0	0
M559	0	0	0	0	0	0	0	0
M553	0	0	0	0	0	0	0	0
M548E1	0	0.1	0	0	0	0.5	0	0.2
M151A2	0	2.8	0	0.9	0	11.2	0	3.7
M715E1	0	1.3	0	0.4	0	4.1	0	1.4
M35A2	0	0.2	0	0.1	0	0.8	0	0.3
M49A2C	0	0.1	0	0	0	0.6	0	0.2
M813	0	0	0	0	0	0	0	0
M821	0	0	0	0	0	0	0	0
M816	0	0	0	0	0	0	0	0
M125E1	0	0	0	0	0	0	0	0
M818-M127A1C*	0	0	0	0	0	0	0	0
TDW901	0	1.3	0	0.4	0	4.1	0	1.4
M60A2	0	0.1	0	0	0	0.2	0	0.1

NOTE: 854 links - average link distance 0.62 miles.

* All values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D9

Percentages of Links With Linear Feature Crossing Times of More Than 10 Min

West Germany

Vehicle	Off-Road* Dry	Wet	Snow	All Surface Conditions
M561	22.0	34.2	34.2	30.1
M656	19.5	34.2	34.2	29.3
M520E1	18.4	34.2	34.2	28.9
M559E1	18.4	34.2	34.2	28.9
M553	19.2	34.2	34.2	29.2
M548E1	11.0	15.6	15.6	14.1
M151A2	25.3	34.2	34.2	31.2
M715E1	23.0	34.2	34.2	30.5
M35A2	19.9	34.2	34.2	29.4
M49A2C	19.9	34.2	34.2	29.4
M813	19.9	34.2	34.2	29.4
M821	17.9	34.2	34.2	28.8
M816	19.8	34.3	34.3	29.5
M125E1	16.0	32.1	32.1	26.7
M818-M127A1C**	19.6	34.2	34.2	29.3
TDW901	18.5	34.2	34.2	29.0
M60A2	9.5	16.9	16.9	14.4

NOTE: 2184 links - average link distance 0.8 miles.

* No vehicles had linear-feature-crossing times more than 10 min on as-is links.

** All values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Average speeds, all vehicles

6. As background for the speed performance figures for individual vehicles, Table D3 presents for the Mid-East and West Germany study areas a broad look at the data as a whole. The ranges of average speeds predicted for all 17 study vehicles under the three conditions and two route interpretations are shown, along with the corresponding simple mean speeds for all vehicles and the standard deviation normalized in the mean (δ/V_{mean}). Two ratios between mean speeds are also shown: the first between the speed with the route considered as an off-road traverse and speed with the route considered as-is (V_{off}/V_{asis}); and the second between mean speed under a given nondry condition and that under dry conditions (V_{cond}/V_{dry}).

7. The first observation from these figures is that average speeds* are low, especially in operations that are all off road. As-is mean speeds in the West Germany area are some 50 percent higher than in the Mid-East area, largely due to the less favorable composition of the route network in the latter, as shown in Table 2 (main text). On the other hand, total off-road operation is generally slower in the West Germany area as a result of greater topographic relief, weaker soils, and forested areas.

8. The low speeds tend to obscure the fact that both significant absolute and large relative speed performance differences occur. As an overall statement, speed differences between the fastest and slowest study vehicles over the links as-is and as off-road traverses are of the order of 8 mph and 3 mph, respectively. More striking is the fact that the fastest vehicle (in a given situation) goes 1.5 to 10 times faster than the slowest, depending on the situation.

9. The ratios V_{off}/V_{asis} are remarkably similar for all conditions in an area but are markedly different for the two areas. The latter reflects the differing relative development of the road networks

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* NOGO and linear-feature-crossing times are included in speed computations in the same way as was done in developing job travel times. See paragraphs 36-40 in the main text.

in the area and the oppositely trending differences in the difficulty of the off-road terrain.

10. Deterioration of speed performance under wet conditions (V_{wet}/V_{dry}) is also markedly similar for the as-is and off-road route interpretations in an area but again differs between areas. The wet season (actually an especially wet season during rain) in the West Germany study area slows the vehicles more because the associated rainfall is higher, and soil strengths are correspondingly reduced by a greater amount.

11. Both the sand condition in the Mid-East area and the snow condition in the West Germany area are to some extent arbitrary, but the figures in Table D3 show, in terms of V_{cond}/V_{dry}, that they are overall slightly more severe than the wet condition for the associated area.

Average speeds, individual vehicles

12. Tables D4 and D5 summarize individual vehicle speed performances in the two study areas under the three ground conditions and both route interpretations. A fourth speed has been added for both link interpretations, which is the average formed on the arbitrary assumption that one third of the distance traveled is under each condition (dry, wet, and sand or snow).* In these tables, the highest speed for a given condition and route is double underlined; the lowest, single underlined. Off-road speeds predicted for the M818-M127A1C semitrailer rig are included but are flagged as suspect for reasons discussed in Appendix A, paragraphs 14, 15, and 17.

13. Perhaps the most important single observation to be drawn from the link speed figures is that the overall speed performance profiles of the GOER vehicles (M520E1, M559, and M553) are qualitatively different from those of all the other military wheeled vehicles. In general, GOER

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* Note that average speed when N equal distances are given is not the simple mean but is

$$V_{av} = \frac{N}{\frac{1}{V_1} + \frac{1}{V_2} \cdots + \frac{1}{V_N}}$$

performance relative to that of the other vehicles is poor to unexceptional in the better operating situations, with a tendency to become acceptable to outstanding in the more difficult situations. Blanket inclusion of the GOER vehicles in the high-mobility fleet tends to distort the picture of high-mobility potential in all but the most severe situations (which did not often occur in the scenario play of either study area).

14. A second important observation is that 1970 technology, represented by the TDW901, 8-ton, 8x8, has the clear potential for providing a relatively outstanding level of performance under all the conditions examined. Using as a reference in each situation the performance of the M60A2, which is one of the principal vehicles currently to be supported in combat, the speed of the TDW901 is generally of the same order for all situations except the full off-road traverse in the Mid-East sand condition (for which the M548E1, like the M60A2, tracked, is a significantly better companion).

NOGO's encountered in the network

15. In determining travel time required by a specific vehicle to accomplish a given job over a given route and under stated conditions, NOGO distances off or on road were considered to be traversed at 0.1 mph, but total NOGO time assessed within a single link was limited to 60 min (paragraphs 36-40 of the main text). Under these rules, the proportion of total travel time assessed for NOGO's for a vehicle operating off road once over each link (used to compute the average speeds just discussed) frequently ranged to over 60 percent for some vehicles and situations, with a mean of approximately 40 percent for all vehicles in all off-road situations. Thus, the vehicles were heavily penalized for NOGO performance, even with the 60-min-per-link maximum in effect.

16. It is an open question as to whether or not these penalties reflect fully the cost of NOGO's in terms of recovery and support resources required from Army elements other than those operating the vehicles. In any event, the GO/NOGO performance of vehicles used for forward area support is a major evaluation element.

17. Tables D6 and D7 summarize the percentage of the entire network for each of the two study areas that is NOGO for each study vehicle under the six surface condition-route interpretation situations evaluated. In addition, the average percentages of travel are shown that would be NOGO if the vehicles were required to travel the network once under each of the three conditions, either with the links as-is or as off-road traverses. Minima for each situation (which, like maximum speed in the previous tables, is the highest performance) are double underlined; maxima, single underlined.

18. Table D6 shows that the wheeled vehicles had the greatest difficulty in the Mid-East study area when it was converted to an all-sand-dune terrain as discussed in the main text, paragraph 15. (The tracked M60A2 and M548E1 had very little difficulty in the same situation.) The GOER vehicles (M520E1, M559, and M553) and the TDW901 faired reasonably well. Fitting suitable sand tires, of larger size and operated at still further reduced inflation pressures, would raise the performance of the other all-wheel-drive wheeled vehicles significantly close to the same levels.

19. The GOER vehicles encountered a significant increase in NOGO areas in the wet conditions in West Germany as compared to the dry (Table D7). Moreover, examination of the detailed data shows that the percentage of off-road areal terrain that is NOGO to the GOER's throughout the entire study area (16.7-16.9 percent) is not uniformly distributed, varying from 2 to over 30 percent in the areas covered by individual topographic map sheets.

20. The GOER mobility problems in the wet conditions can be traced directly to weak soils, which, even when adequate to support the vehicle in simple, level terrain areas, reduce capabilities on slopes, in negotiating obstacles, and in pushing over trees, required in more complex areas. Although the terrain modeling used in the study tended to bias soil performance somewhat in favor of small vehicles and against larger vehicles (Appendix A, paragraph 39), comparison of the percent NOGO's in the same wet conditions for the 8-ton GOER's (16.7-16.9 percent) with that for the 8-ton TDW901 (3.3 percent, and best for any of

the study vehicles) shows that the large vehicles were not necessarily treated unfairly. The trend shown is considered correct.

21. In both study areas the tracked M60A2 and M548E1 show significant increases in NOGO situations from the dry to wet conditions. This is due in part to soil slipperiness problems arising from the rainfall which was part of the wet (study) condition, as well as to the reduced soil strengths associated with the seasonal wetness. Many soils, still amply strong to permit ready motion in simple level terrain, become treacheously slippery when wetted. Traction potential needed for slope climbing, obstacle negotiations, etc., is significantly reduced, especially for tracked vehicles fitted with track road pads. The M548E1 is normally fitted with such pads. The M60A2 when running on the rubber chevron track (T96) is effectively on road pads; when on the newer T142 track, is actually on them.

Travel time spent in crossing linear terrain features

22. The time assessed for crossing rivers, streams, canals, embankments, and similar linear terrain features during off-road travel averages 0.5 to 1 min per mile in the Mid-East study area, and 4 to 21 min per mile in the West Germany study area, depending on the vehicle and conditions. On the off-road links in the Mid-East study area, these times generally constitute only 1 to 4 percent of the total travel time, but in the West Germany study area they are of the order of 40 percent of the total. The total linear-feature-crossing time consists of two components: (a) times of a fraction of a minute to a few minutes each to cross individual features that present relatively little difficulty, and (b) longer times associated with crossings that constitute potential barriers.

23. Tables D8 and D9 show each vehicle the percentages of all links in the Mid-East and West Germany study areas, respectively, which involved a total linear-feature-crossing time in excess of 10 min. No distinction is made in these figures between links in which total time greater than 10 min is reached because of a great many crossings of only nominal difficulty, or because of one or more crossing of features that

were in fact major barriers. Subsidiary figures show that the mean crossing time assessed specifically in the links, where crossing times were greater than 10 min, is generally nearly 60 min, which is the maximum crossing time allowed per link (main text, paragraphs 39 and 40). The implication is that the statistics in Tables D8 and D9 relate to links in which major difficulties occurred.

24. In the Mid-East study area as sampled by the scenario routes,* the linear features caused special difficulties only in the wet condition when small drainage features carry water, wadis are flooded, and soils were slippery. Slipperiness appears to have affected the two tracked vehicles (M60A2 and M548E1) and the wheeled TDW901 and M561 (because of relatively low-pressure tires). The relatively small M151A2, the M715E1, the two 2-1/2-ton trucks (M35A1 and M49A2C), and the TDW901 appear to have encountered fording problems as well.

25. In the West Germany area, there were no linear feature crossings in the as-is route. The off-road routes, however, involved many. Approximately 30 percent of all links involved trouble for the wheeled vehicles; 15 percent, for the two tracked vehicles. Variations in the performances of individual vehicles of either type is so small as to be insignificant, despite the fact that both groups include vehicles with and without inherent swimming capabilities.

Off-road speed profiles

26. In the 1972 DA WHEELS Study[1] off-road speed profiles (there referred to as mobility profiles) were used as a principal means of displaying the area-wide off-road performance in areal terrain of the vehicles involved. The off-road speed profile for a given vehicle in a given terrain and condition shows the average speed the vehicle can sustain, as a function of the percentage of the total area under consideration that it avoids, under the assumption that it avoids those areas posing the greatest impediment to its motion. The profile conveys a complete statistical description of the vehicle's mobility performance in areal terrain in all aspects save spatial distribution.

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* One significant river in the area was not crossed at any time in the map play.

27. AMM areal terrain speed predictions were run for all vehicles and conditions in the link traverse sample (paragraph 4) of the areal terrain characterized for one full topographic map sheet in each study area. The single map sheet selected for each area, covering 13 percent of the total Mid-East study area and 16 percent of the West Germany study area, is considered to be representative of the entire area, but some variations occurred. For example, the sample subarea covered by the single map sheet selected for West Germany contained somewhat more forested land and less bottom land where soils would be significantly weakened in wet conditions than did the West Germany study area as a whole.

28. The off-road speed profiles derived from the AMM predictions for the sample subareas are shown in Figures D1-D12. Profiles for the vehicles in the study high-mobility fleet are presented in the odd-numbered figures; for the standard fleet in the even-numbered ones. To facilitate comparisons, the profiles for the M60A2 and the M151A2 are given in both sets. Each profile ends in a tick mark denoting the percentage of area beyond which all remaining areal terrain is NOGO for the vehicle.

29. Large differences in speed performance are apparent among the vehicles in the better terrain for each area and condition (low values for "percent total area"). Although the absolute speeds of the percent of total area at which NOGO's begin are smaller, the relative differences between vehicles are still large.

30. The GOER vehicles (M520E1, M559, and M553) among the high-mobility fleet and the semitrailer rig (M818-M127A1C) in the standard fleet are consistently, markedly slow. The big and very important difference between the GOER's and the semitrailer rig is that the former continue to GO throughout a significantly larger percentage of each area (even though, for reasons discussed in Appendix A, paragraphs 15, 16, and 17, all NOGO's for the semitrailer combination were probably not called in AMM).

31. When speeds of the standard- and high-mobility fleet vehicle of the same payload rating are compared over the full range of GO areas,

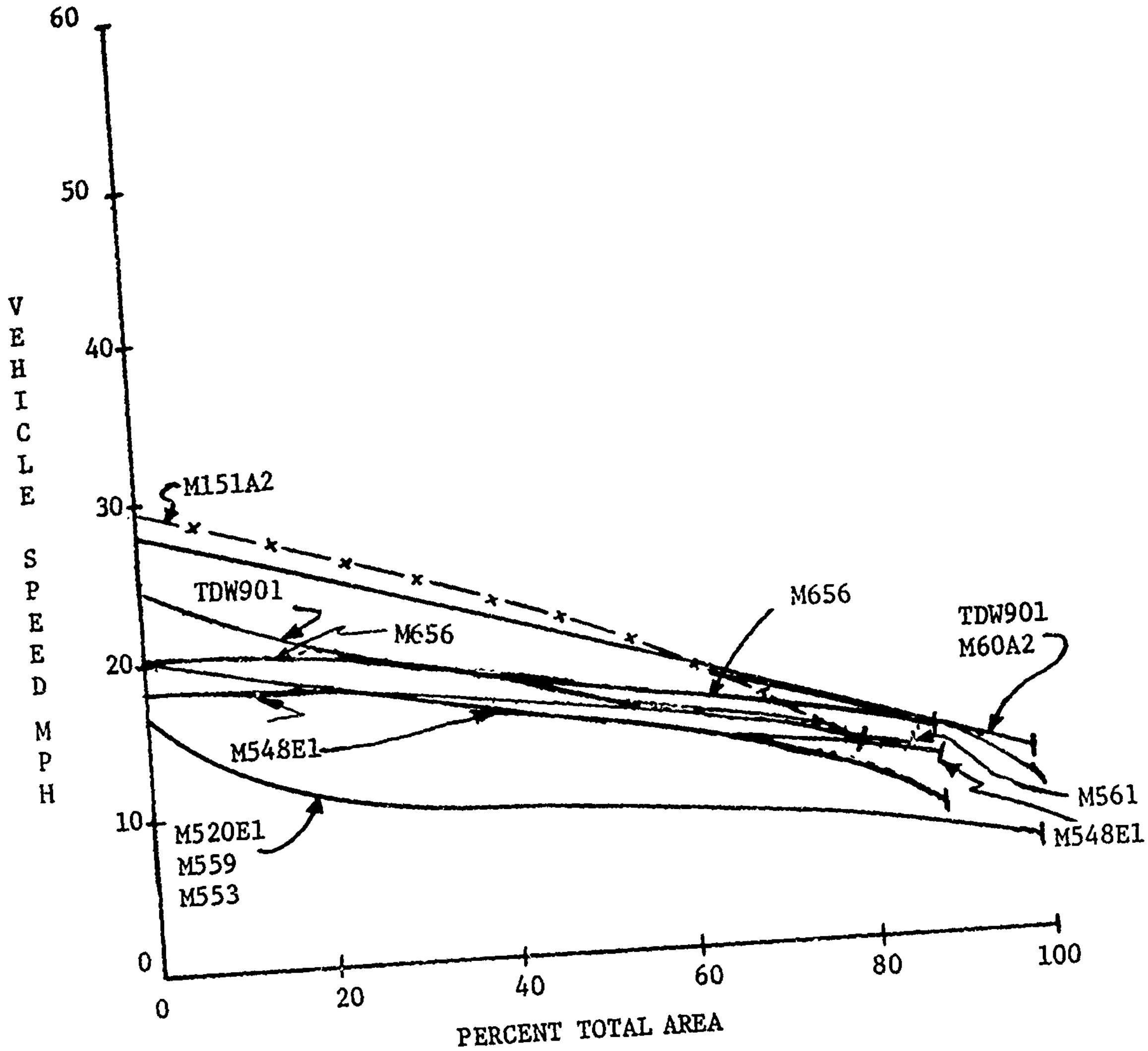
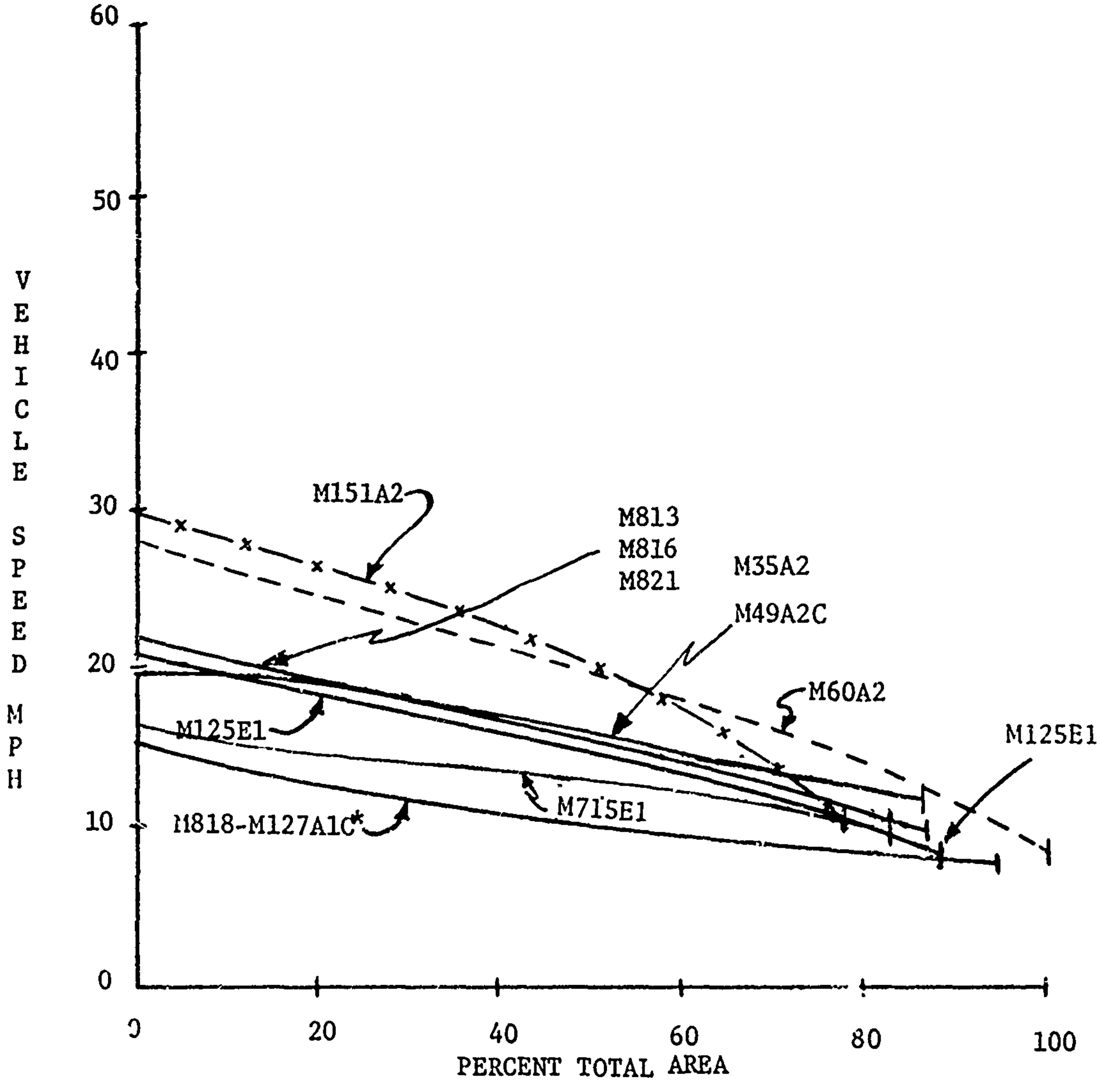


Figure D1. Off-road profiles for high-mobility and reference vehicles, Mid-East, dry condition



* Speeds in conditions approaching the final GO speed are suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Figure D2. Off-road profiles for standard-mobility reference vehicles, Mid-East, dry condition

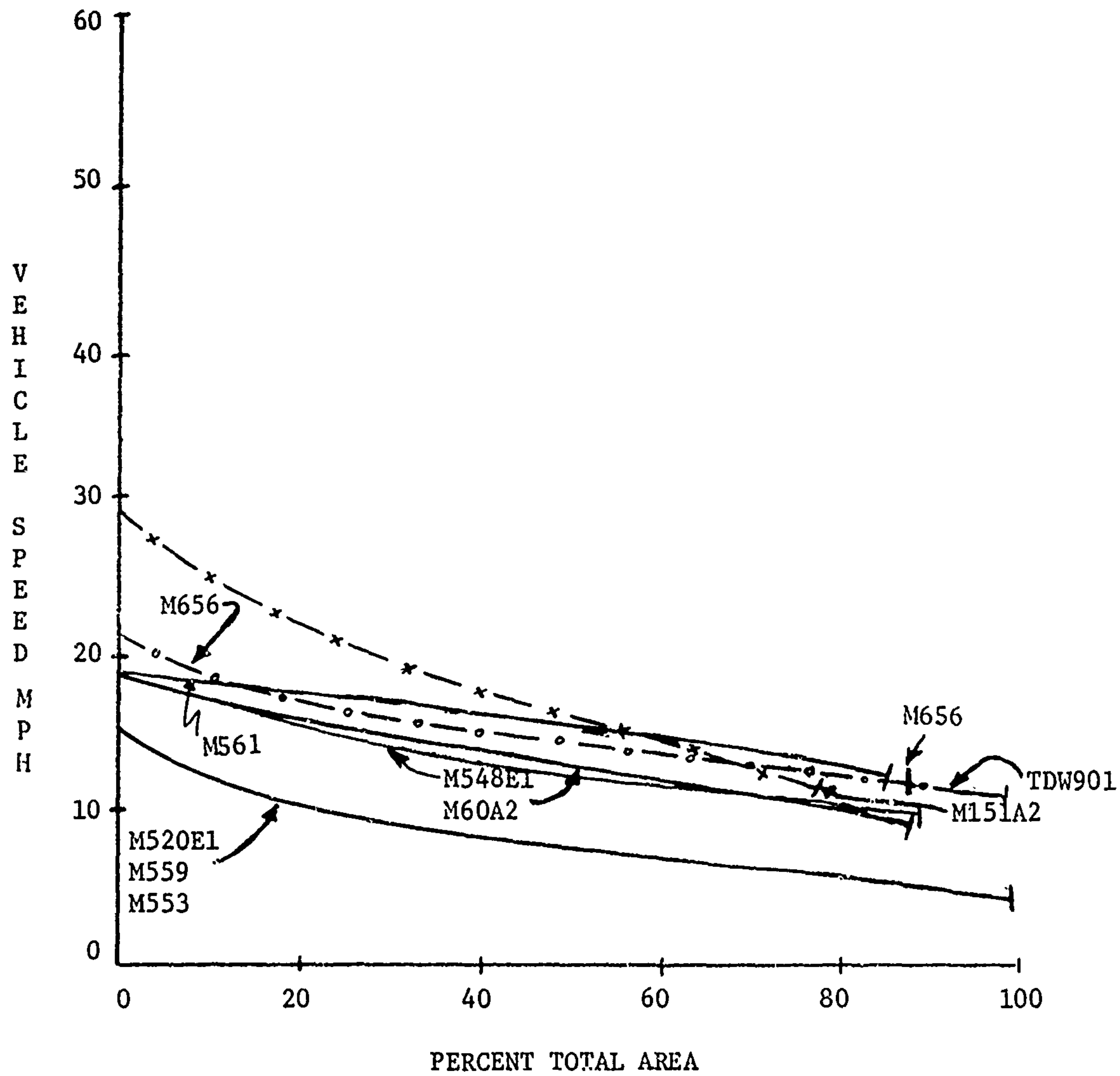
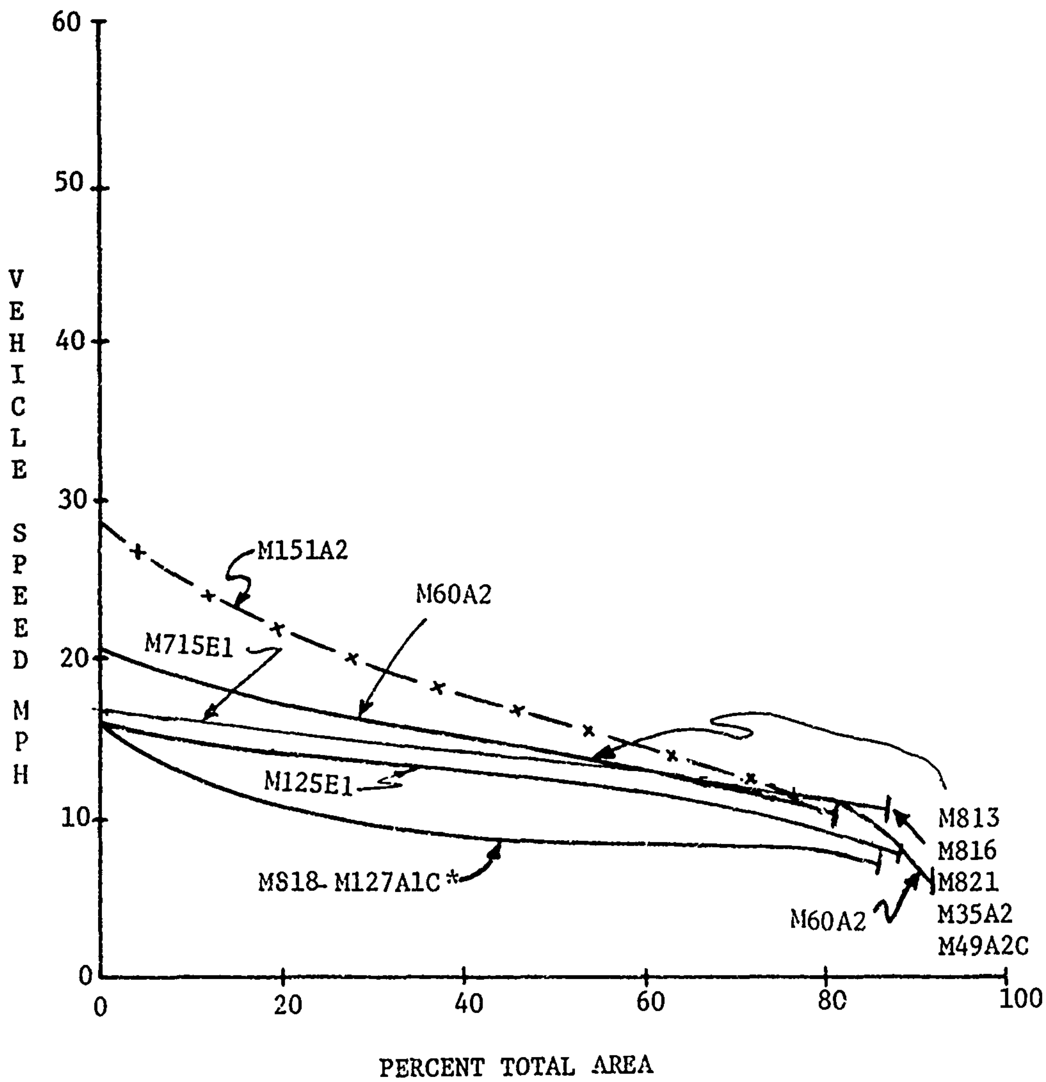


Figure D3. Off-road speed profiles for high-mobility and reference vehicles, Mid-East, wet condition



* Speeds in conditions approaching the final GO speed are suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Figure D4. Off-road speed profiles for standard-mobility reference vehicles, Mid-East, wet condition

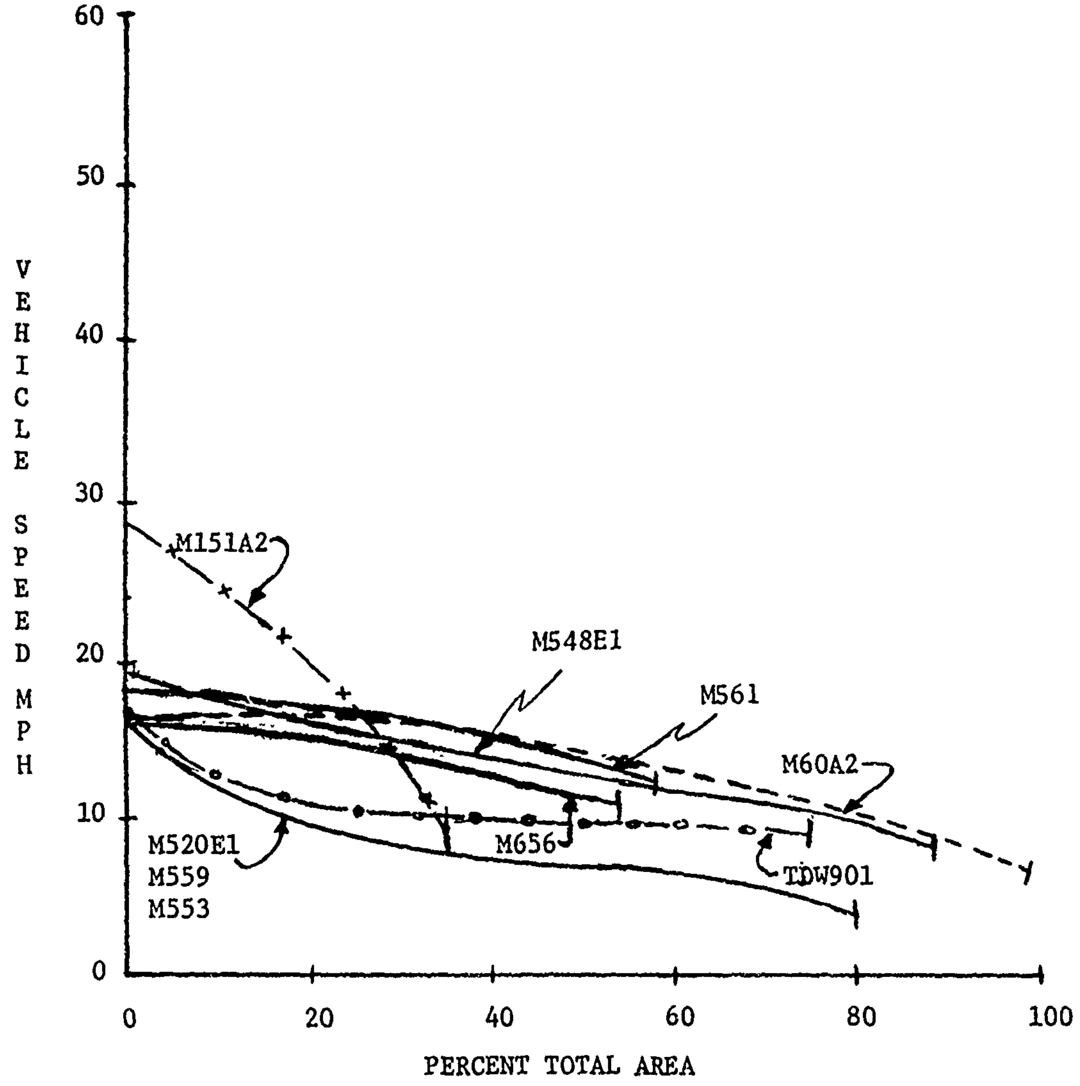
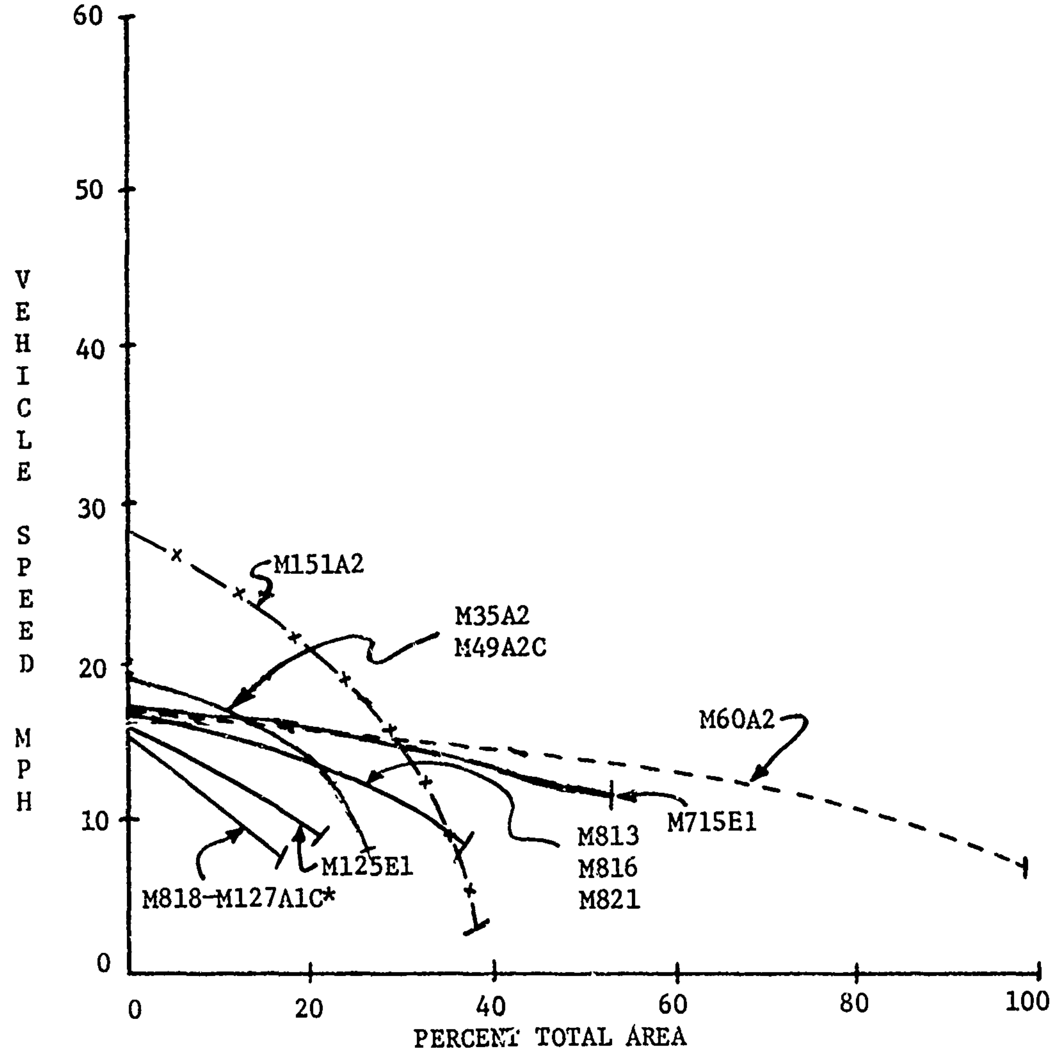


Figure D5. Off-road speed profiles for high-mobility and reference vehicles, Mid-East, sand condition



* Speeds in conditions approaching the final GO speed are suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Figure D6. Off-road speed profiles for standard-mobility reference vehicles, Mid-East, sand condition

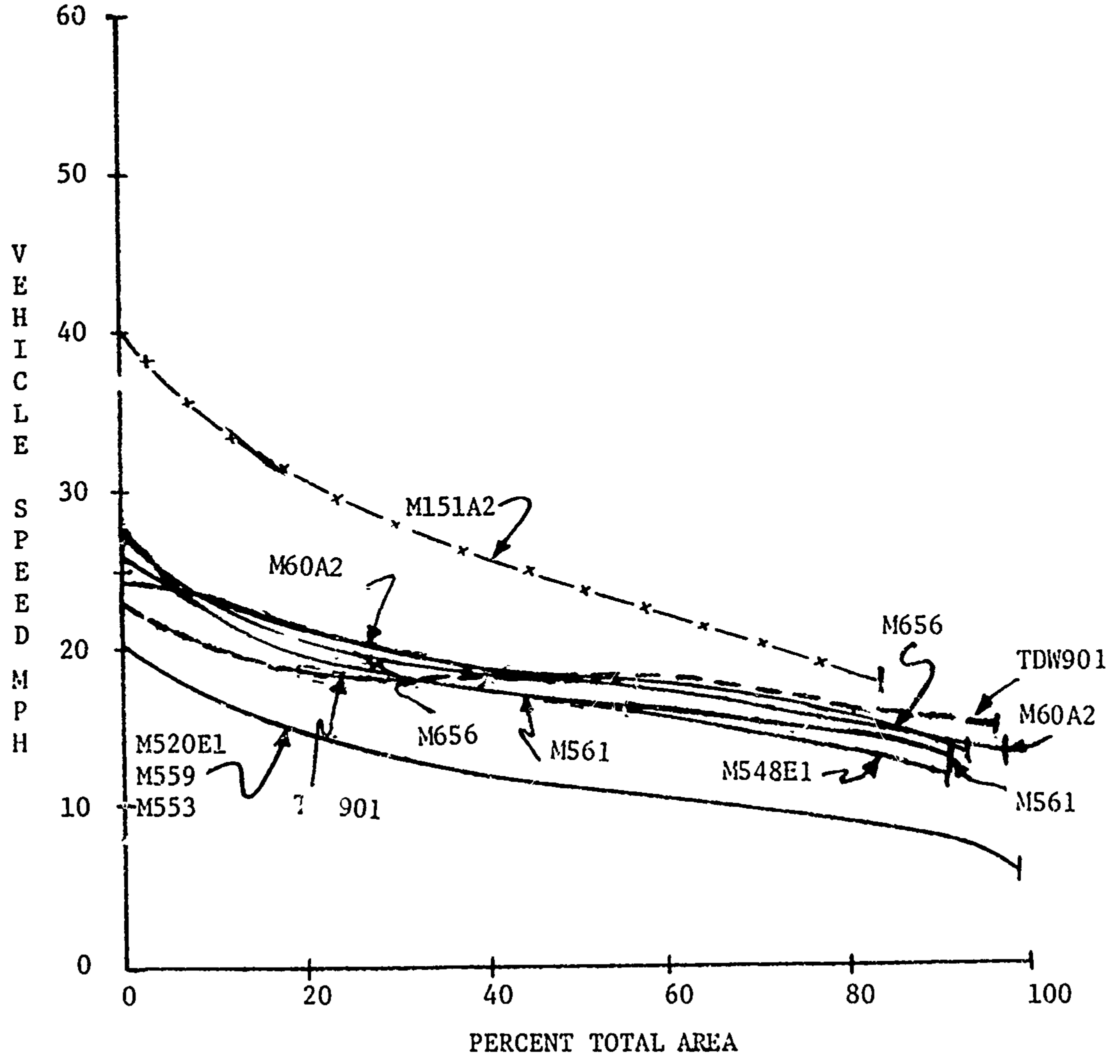
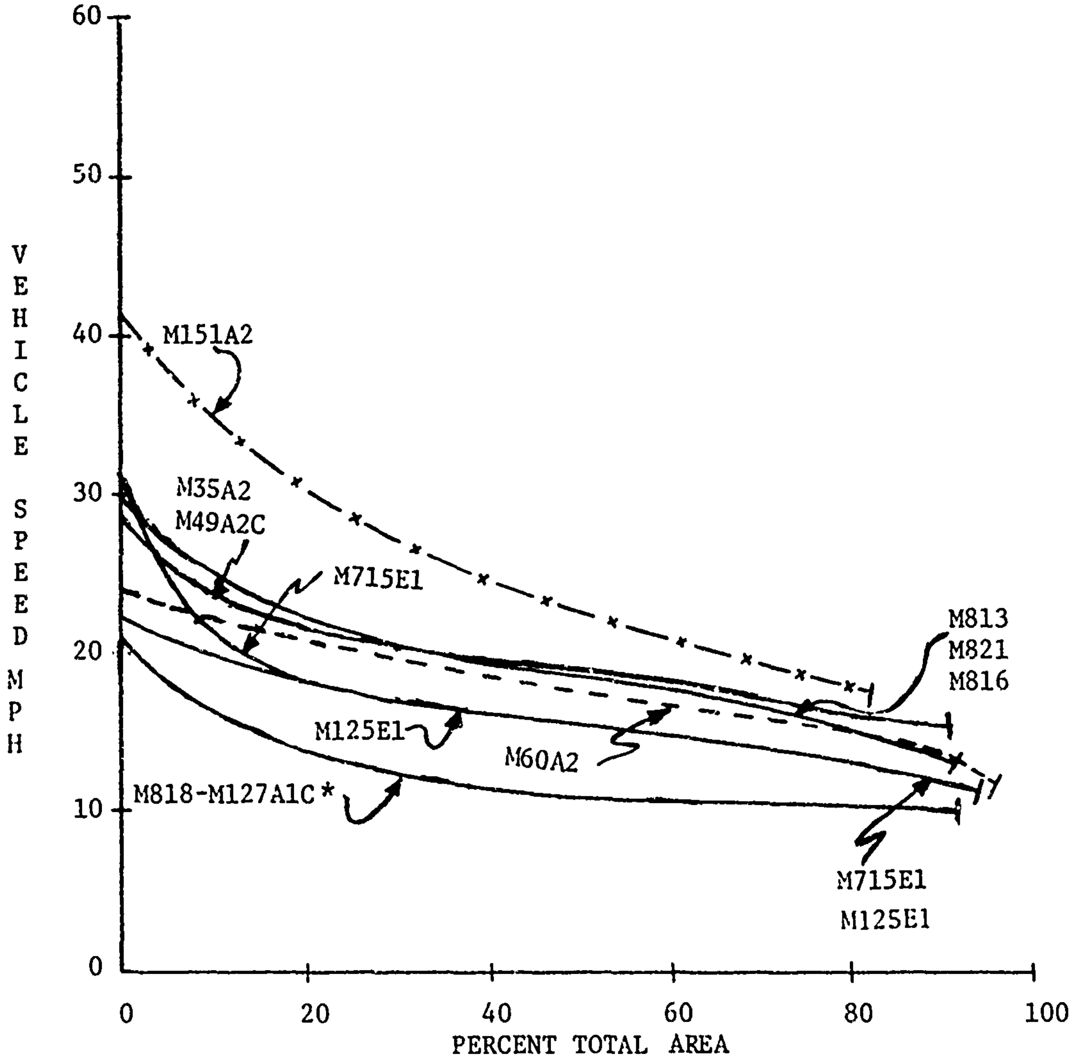


Figure D7. Off-road speed profiles for high-mobility and reference vehicles, West Germany, dry condition



* Speeds in conditions approaching the final GO speed are suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Figure D8. Off-road speed profiles for standard-moility and reference vehicles, West Germany, dry condition

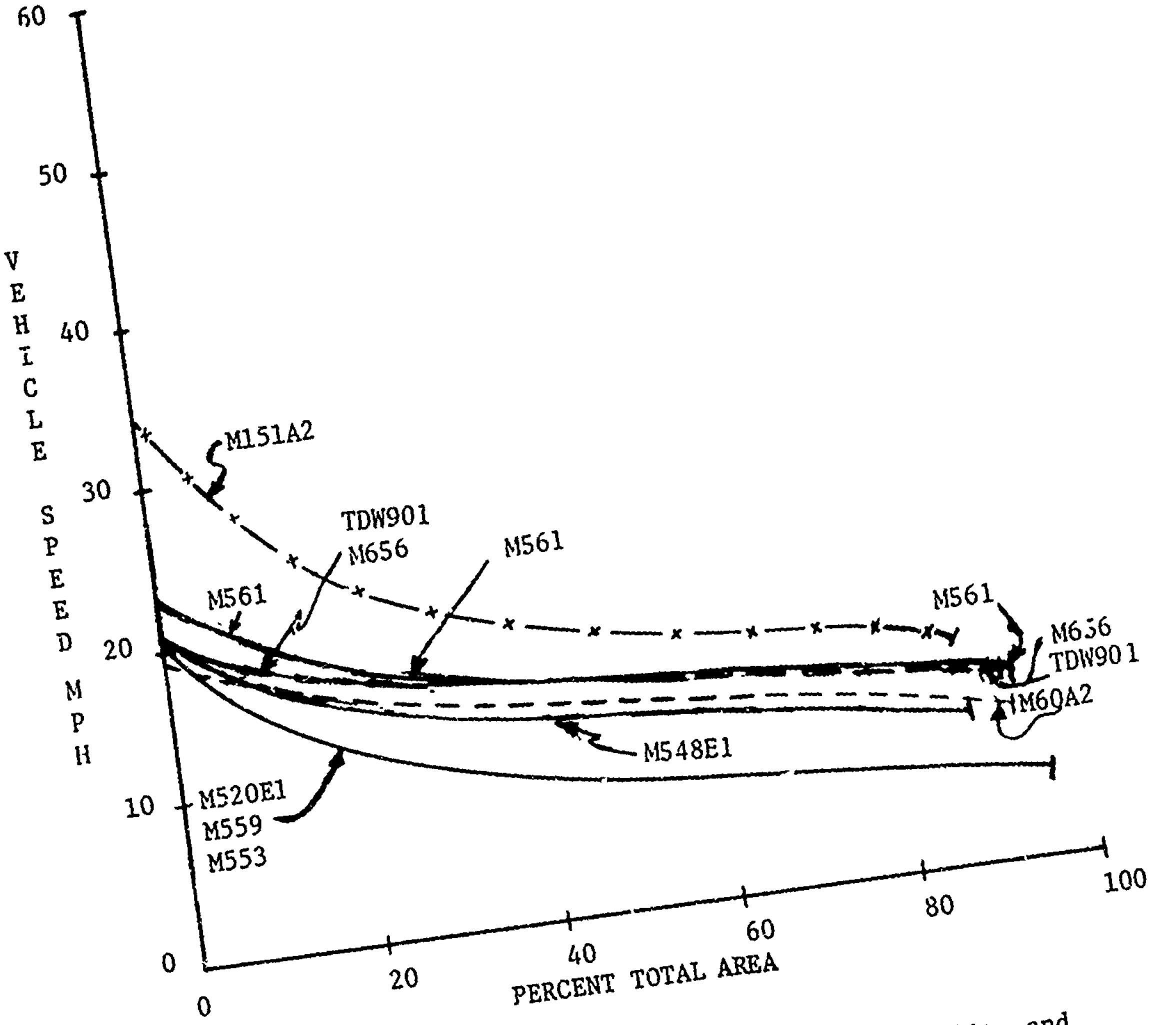
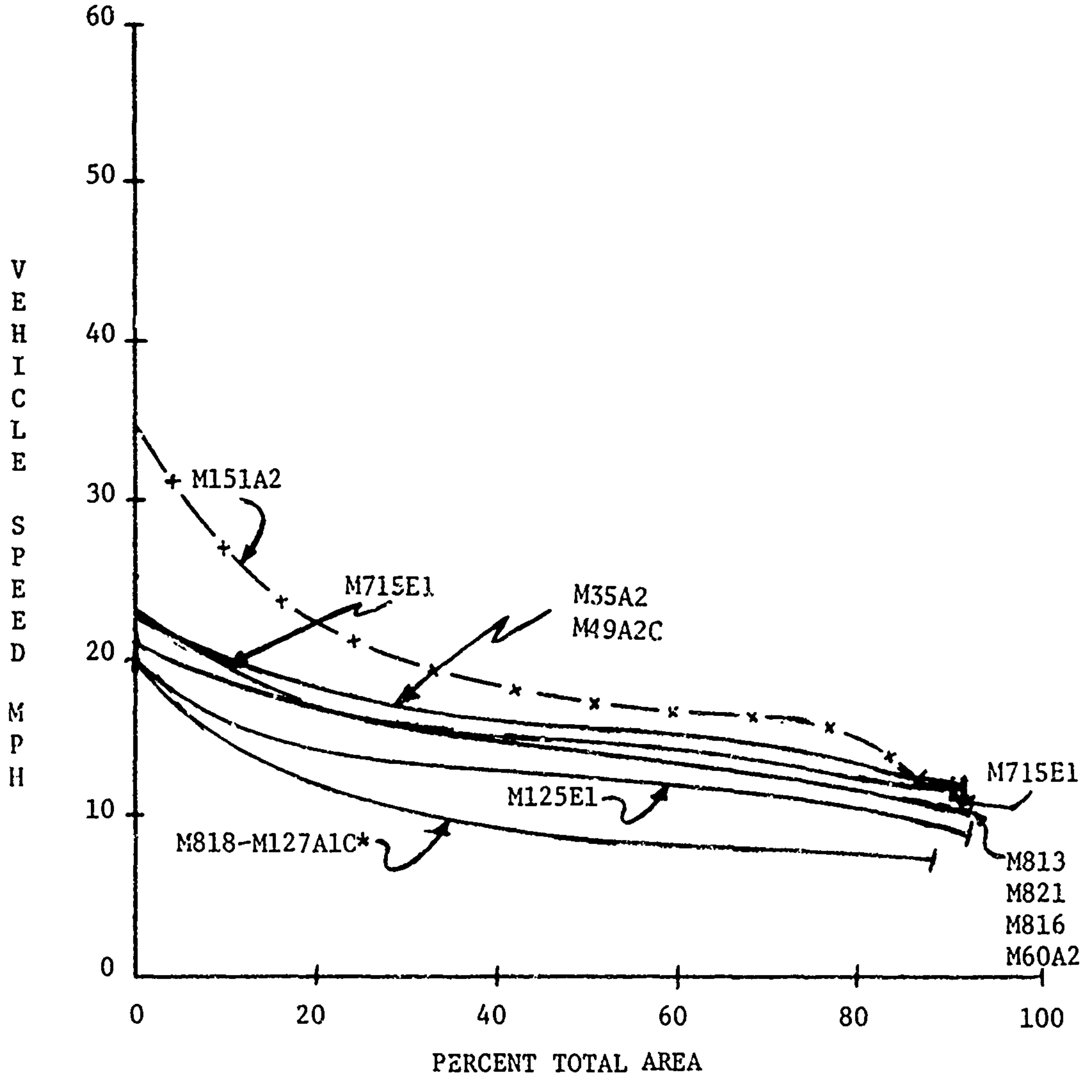


Figure D9. Off-road speed profiles for high-mobility and reference vehicles, West Germany, wet condition



* Speeds in conditions approaching the final GO speed are suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Figure D10. Off-road speed profiles for standard-mobility and reference vehicles, West Germany, wet condition

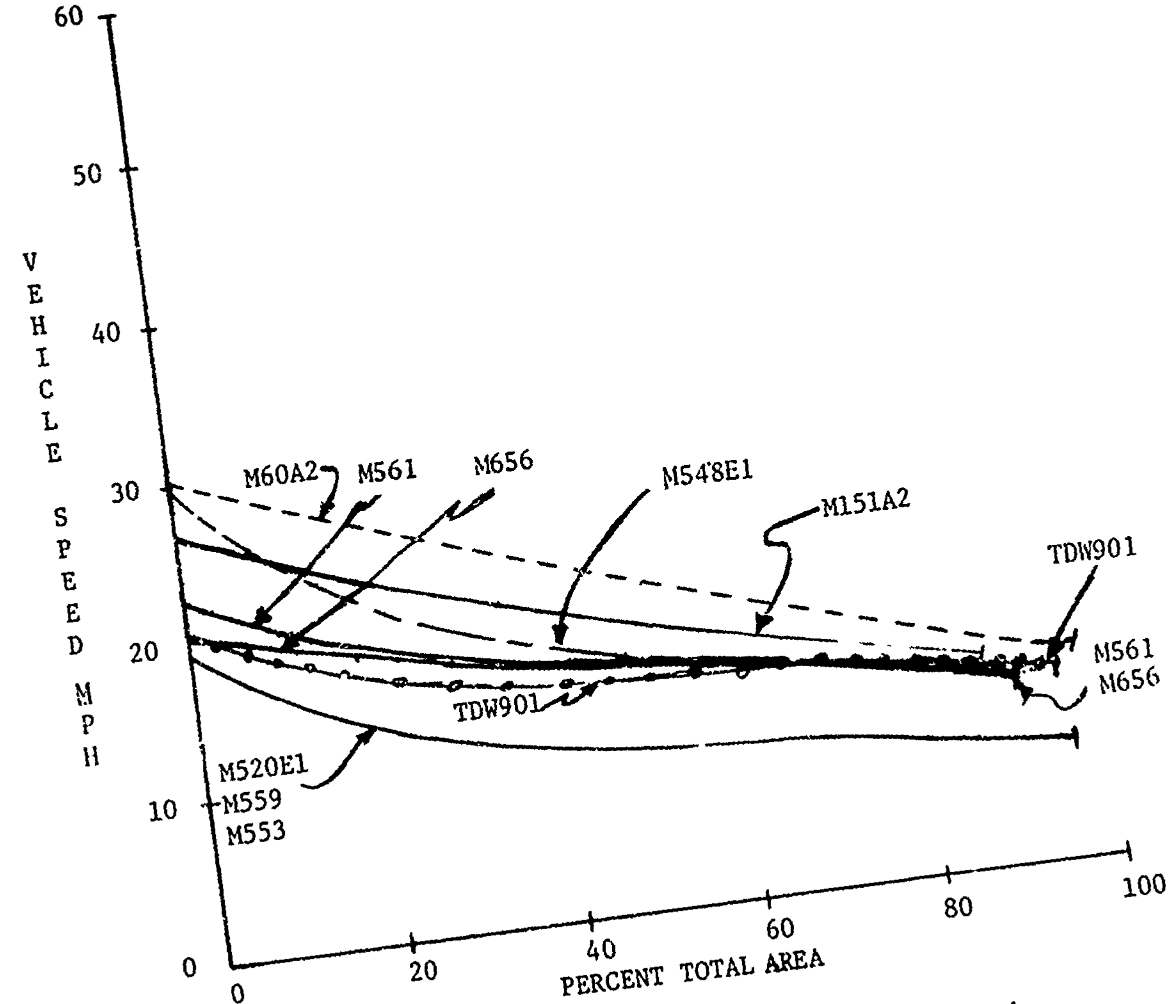
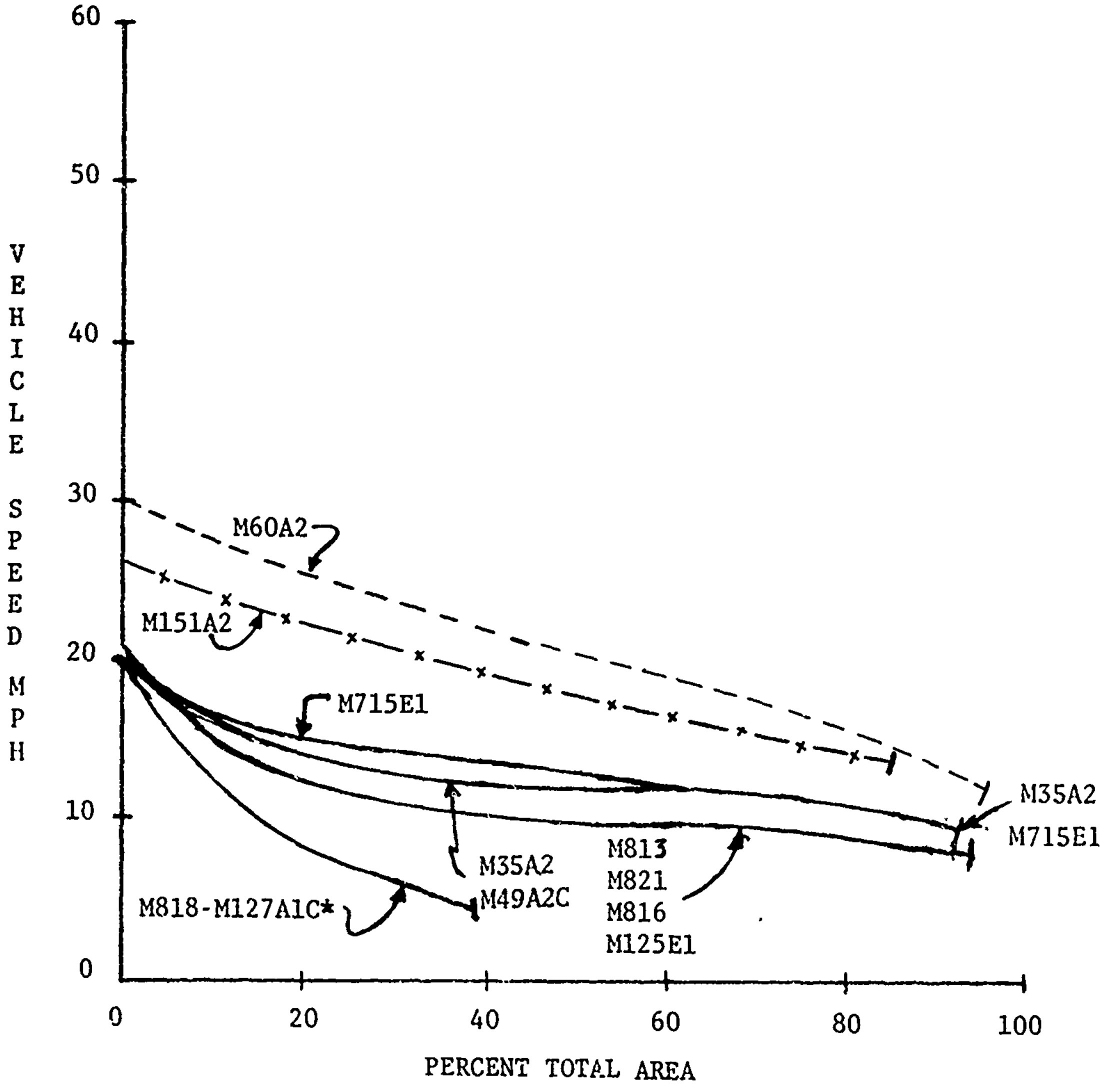


Figure D11. Off-road profiles for high-mobility and reference vehicles, West Germany, snow condition



* Speeds in conditions approaching the final GO speed are suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Figure D12. Off-road profiles for standard-mobility and reference vehicles, West Germany, snow condition

the M561 equals or outperforms the M715E1 (1-1/4-ton vehicle) in all cases; the M656 equals or outperforms the M813 (5-ton) in most cases; and the TDW901 considerably outperforms the GOER's (8-ton) in all cases. The GO speed performance of the 5-ton M656 is marginally better than that of the 8-ton TDW901 in most cases, but the situation is reversed in the Mid-East study area, dry condition.

32. Using the speed for 50 percent of the area (V_{50}) as a basis, the relative speeds of vehicles compared in paragraph 31 are quantified in Table D10. These figures indicate that the newer, higher-mobility vehicle in each weight class (considering that the TDW901 is newer and has higher mobility than the GOER's) consistently show appreciable gains in areal terrain performance over the older, less capable vehicles.

33. Two performance indices have been derived from the off-road speed profiles. The first, used to make discriminations in the 1972 DA WHEELS Study,[9] is the average areal terrain speed when the vehicle is avoiding the 10 percent of areal terrain that is most difficult (V_{90}). The second, termed the cross-country mobility index (I_{cc}), is currently under study by TACOM. I_{cc} is proportional to the second moment of the entire off-road speed profile about the (Y) axis. This index weighs the average speed at a given percent-of-area according to that percent squared, and accordingly it is highly sensitive to average speed for high percents and relatively insensitive to average speeds at low percents. When percent NOGO exceeds 10 percent the WHEELS index, V_{90}, even more than I_{cc}, is highly sensitive to percent of area NOGO.

34. Table D11 shows the WHEELS Study index (V_{90}) for all of the study vehicles in the selected samples of the two study areas, each for three conditions. Table D12 shows the corresponding TACOM cross-country mobility index (I_{cc}) for all vehicles and conditions, based on the same speed profiles.

35. The intent of both indices is to reduce to a single number a highly complex set of numbers, which already involve considerable aggregation to represent a still more complex real-world situation. A decision-maker working with one table or the other could in some instances reach different conclusions. Confronted with both, he might

Table D10

Relative V_{50} for Selected Study Vehicles

	$V_{50,A}/V_{50,B}$ percent					
	Mid-East			West Germany		
Vehicles	Dry	Wet	Sand	Dry	Wet	Snow
1-1/4-ton trucks M561/M715E1	118	117	128	110	104	120
5-ton trucks M656/M813	111	105	115	100	103	149
8-ton trucks TDW901/M520E1	194	179	147	146	169	140
HIMO 5-ton vs 8-ton M656/TDW901	97	101	106	102	107	106

Table D11

WHEELS Study Off-Road Performance Indices (V_{90}) for Study Vehicles

	V_{90} Speeds, mph					
	Mid-East			West Germany		
Vehicle	Dry	Wet	Sand	Dry	Wet	Snow
M561	1.3	1.3	0.2	13.7	12.1	12.4
M656	2.6	2.5	0.3	14.1	11.9	12.3
M520E1	6.0	5.3	0.7	7.9	6.1	7.2
M559	5.8	5.3	0.7	7.6	6.1	7.0
M553	5.9	5.3	0.7	7.7	6.1	7.0
M548E1	4.6	2.6	3.2	12.3	3.0	12.3
M151A2	0.8	0.8	0.2	1.4	2.2	2.2
M715E1	1.0	1.0	0.2	11.6	10.9	10.0
M35A2	1.8	1.8	0.1	14.9	12.8	10.2
M49A2C	1.8	1.8	0.2	14.9	12.8	10.2
M813	2.9	4.3	0.2	12.3	10.4	8.3
M821	4.0	3.7	0.1	11.6	9.2	7.2
M816	2.5	1.9	0.2	11.4	8.7	6.9
M125E1	8.8	6.7	0.1	11.7	9.4	8.1
M818-M127A1C*	7.7	6.1	0.1	9.1	3.6	0.2
TDW901	12.9	11.2	0.6	14.0	11.5	12.0
M60A2	11.3	8.4	8.3	13.5	9.9	13.6

* All values suspect because some NOGO's probably are not called (Appendix A, paragraphs 14-17).

Table D12

TACOM Cross-Country Mobility Indices (I_{cc}) for Study Vehicles

Vehicle	Mid-East Dry	Mid-East Wet	Mid-East Sand	West Germany Dry	West Germany Wet	West Germany Snow
M561	29.8	29.6	10.4	41.8	36.8	37.8
M656	33.8	29.8	7.6	44.0	37.4	38.8
M520E1	23.6	20.4	11.8	30.4	22.4	27.2
M559	23.2	20.6	11.2	29.6	22.6	26.2
M553	23.2	20.8	11.2	29.6	22.6	26.2
M548E1	32.2	27.0	26.6	38.2	28.6	38.0
M151A2	30.4	26.0	3.2	44.4	37.8	38.4
M715E1	24.4	24.4	7.2	37.4	34.8	31.6
M35A2	32.0	29.0	1.4	46.4	39.2	31.0
M49A2C	32.0	29.0	1.4	46.4	39.2	31.0
M813	31.6	28.0	2.8	42.2	34.4	26.2
M821	33.0	26.2	0.6	39.0	30.0	23.4
M816	29.8	22.6	3.2	38.4	27.4	22.4
M125E1	31.6	26.4	1.0	39.6	30.6	26.2
M818-M127A1C*	27.0	21.4	0.6	28.8	21.0	2.0
TDW901	46.2	39.6	15.2	46.0	37.8	39.4
M60A2	49.0	30.6	34.6	48.8	34.0	51.0

* Values suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

well be confused. I_{cc} is to be preferred to V_{90} as a decision number because it reflects the characteristics of the entire profile, but its relation to the tasks which must be done is abstract. Despite the evident dangers involved, a third single number "rating speed," which is thought to be more relevant, is developed for the vehicles in the main text (paragraphs 84-95). The reader is accordingly left to his own devices in attemping to interpret the meaning of either V_{90} or I_{cc} in terms of the HIMO Study objectives.

On-road speed profiles

36. The area-wide performance of the vehicles on the roads and trails and on the few off-road traverses included in the MSR network as-is can be displayed in on-road speed profiles similar to the off-road speed profiles. Figures D13-D20 show the on-road speed profiles for the study vehicles in the same subareas used to make the off-road speed profiles. Profiles for the dry conditions in both study areas are not included, because they were only slightly different (better) than profiles for the wet conditions.

37. Many of the NOGO's are associated with trail operation, which, when the trails become sand trails in the Mid-East area sand condition, essentially constitute an off-road challenge that is formidable to all of the wheeled vehicles. Because of the generally better roads in the West Germany study area, the profiles are somewhat less sensitive to percentage of distance than in the Mid-East study area.

38. In Table D13 are, for the on-road situation, the same comparisons as in Table D10 (M561 versus M715E1, M656 versus M813, TDW901 versus M520E1, M656 versus TDW901). The comparisons in this case, however, are based on speed performance over all superhighways and primary and secondary roads, plus the 10 percent of trails and as-is off-road traverses that present the least mobility difficulty (main text, paragraph 86).

39. The same orders of relative speeds are seen on road as was shown for areal off-road conditions, except that the M813 performance is essentially the same as that of the M656 in wet and dry conditions in both study areas. The 5-ton M656 speed superiority over the 8-ton

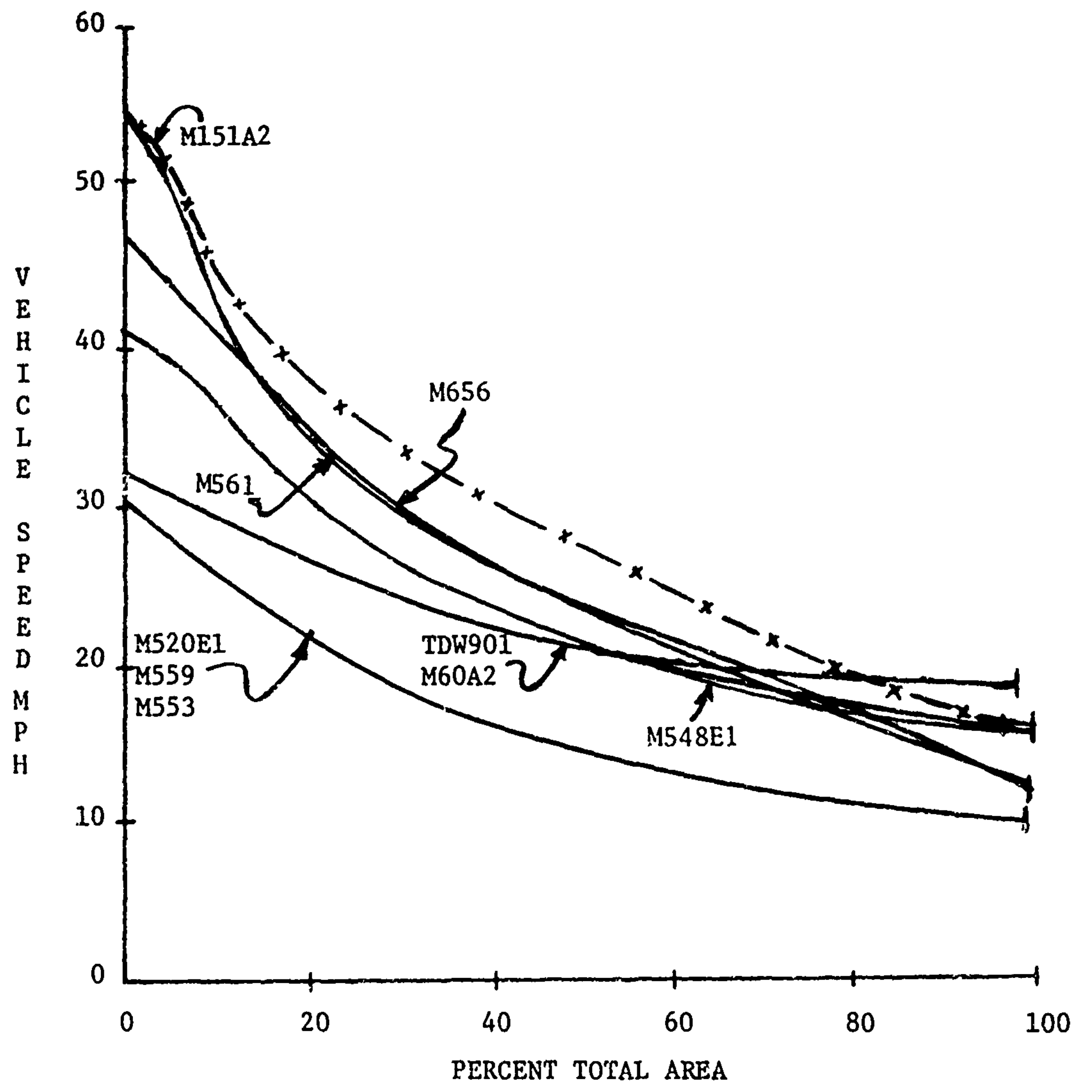
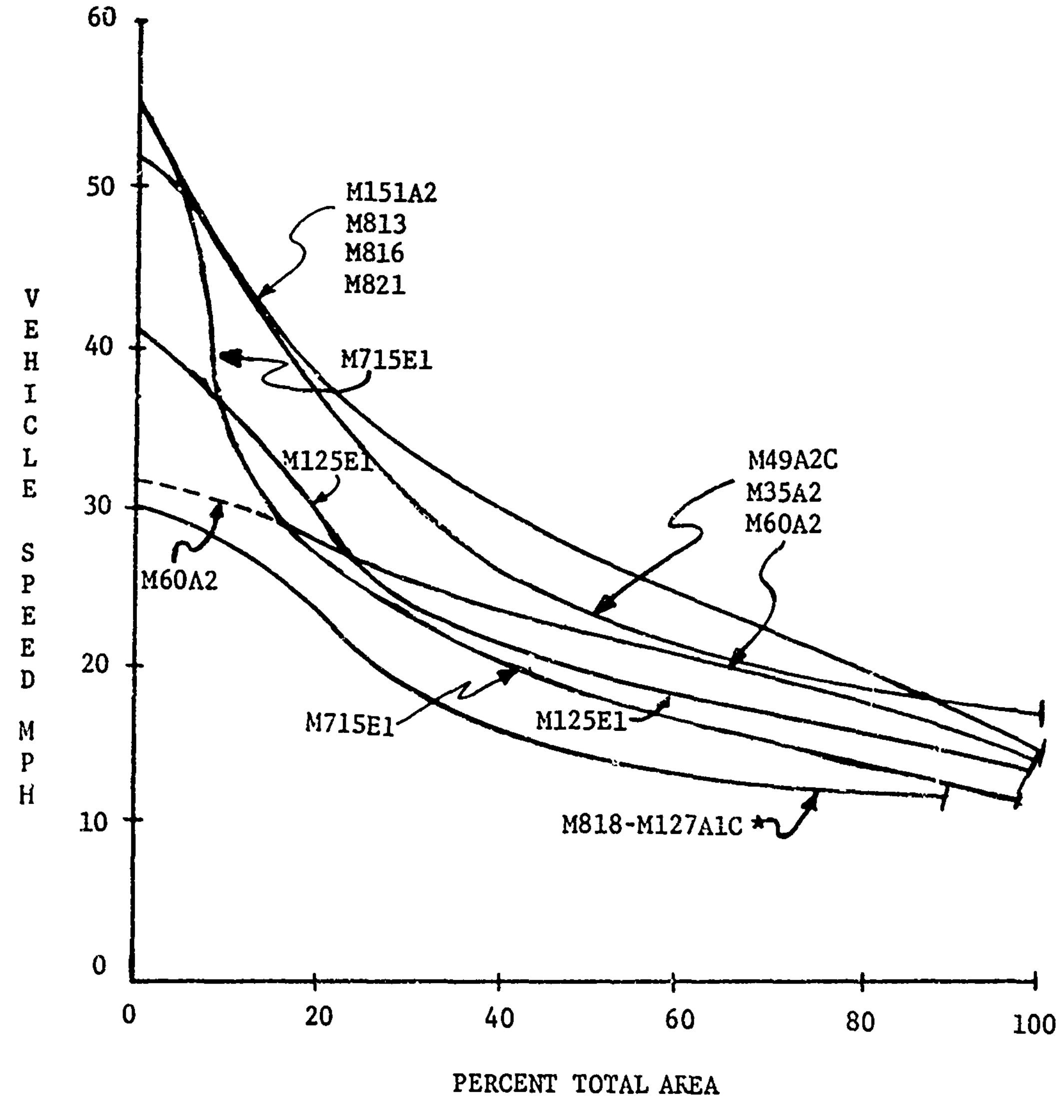


Figure D13. On-road speed profiles for high-mobility and reference vehicles, Mid-East, wet condition



* Speeds in conditions approaching the final GO speed are suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Figure D14. On-road speed profiles for standard-mobility and reference vehicles, Mid-East, wet condition

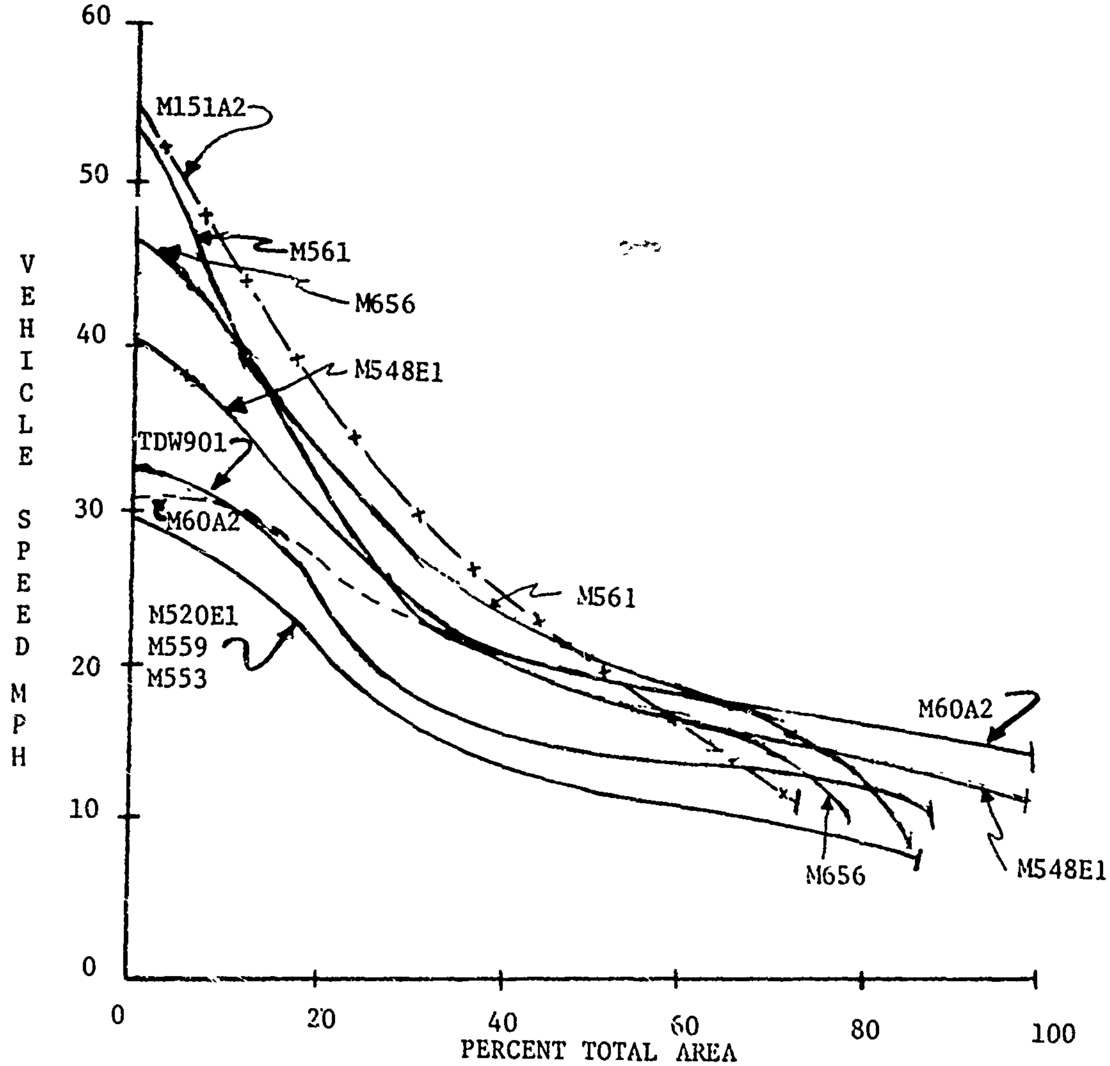
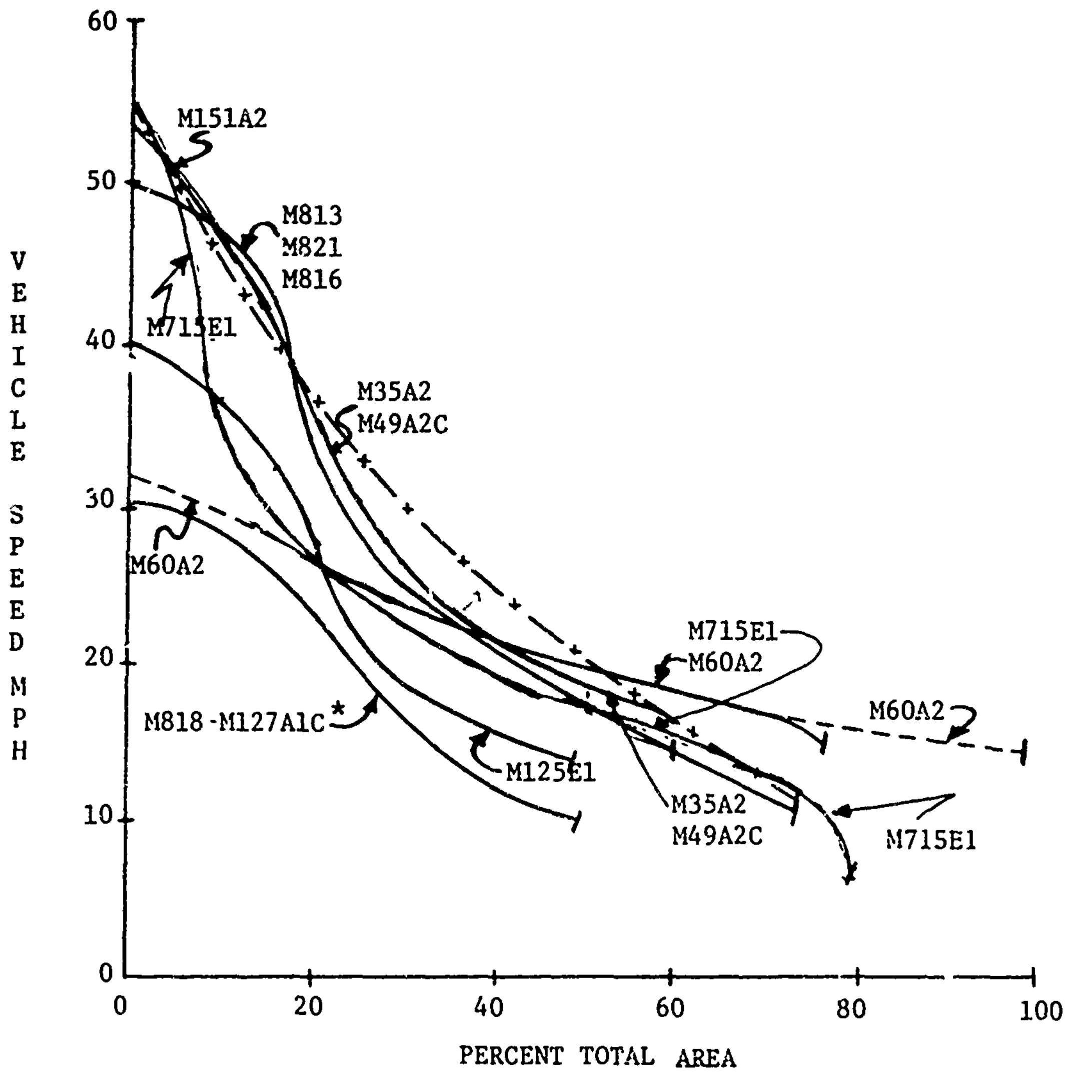


Figure D15. On-road speed profiles for high-mobility and reference vehicles, Mid-East, sand condition



* Speeds in conditions approaching the final GO speed are suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Figure D16. On-road speed profiles for standard-mobility and reference vehicles, Mid-East, sand condition

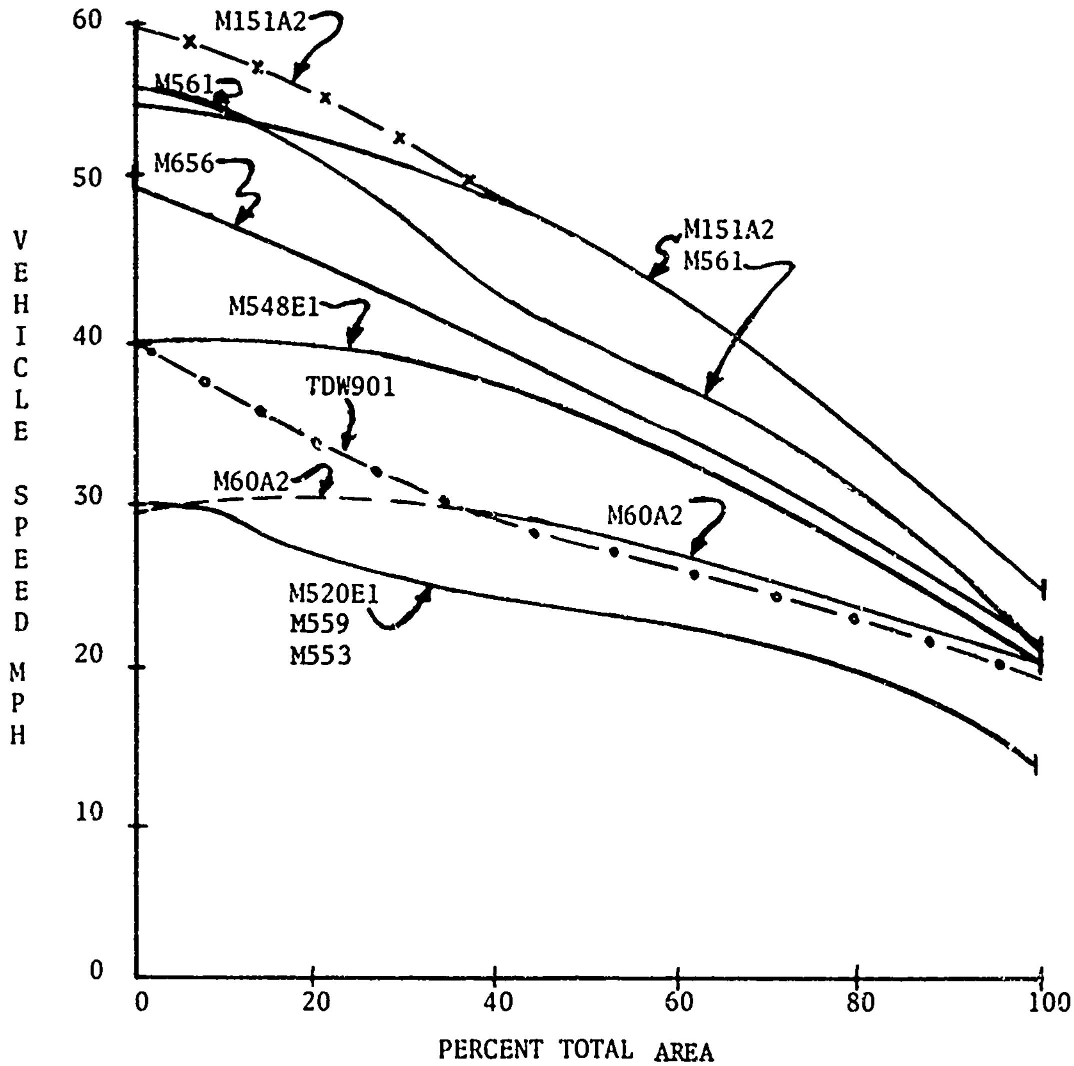
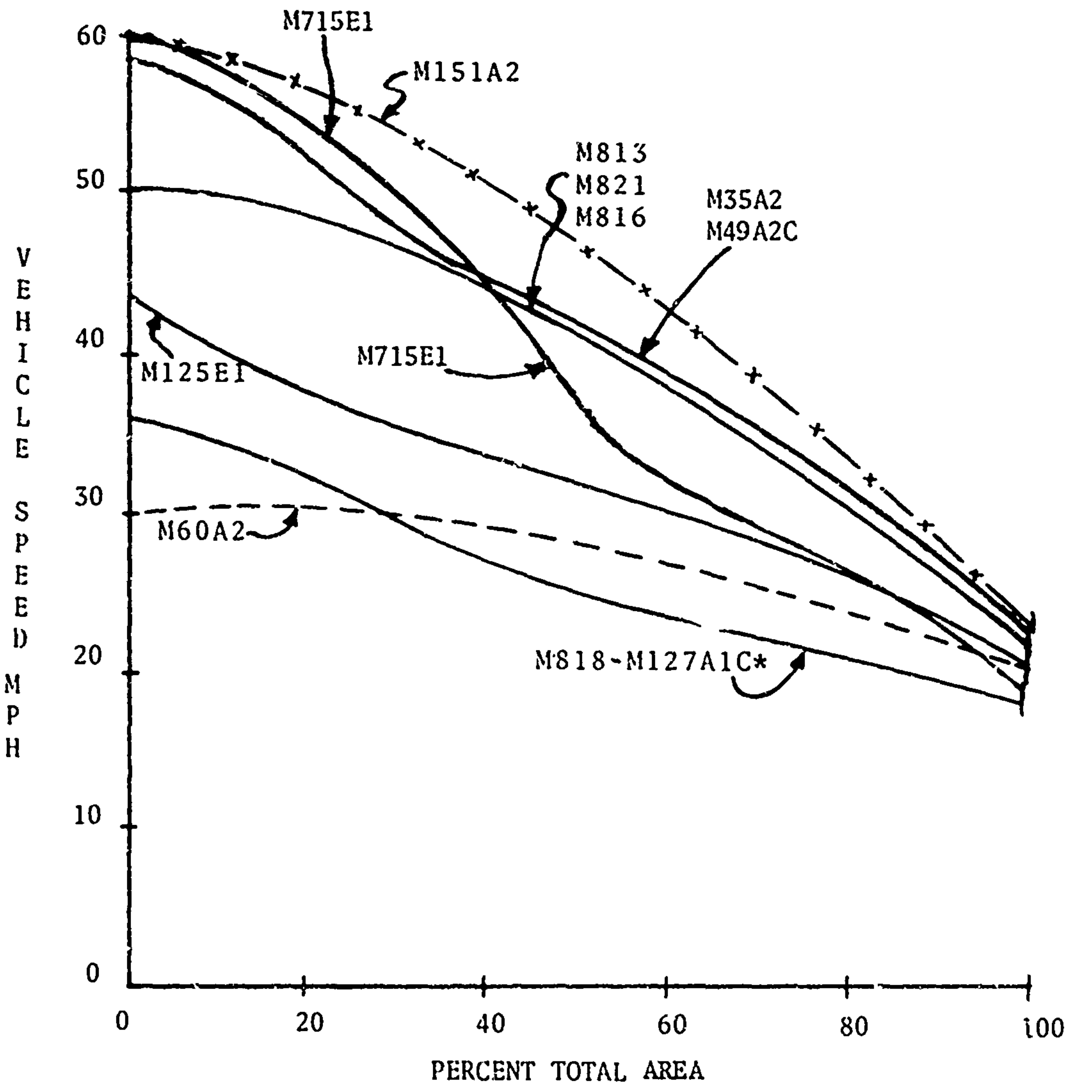


Figure D17. On-road speed profiles for high-mobility and reference vehicles, West Germany, wet condition



* Speeds in conditions approaching the final GO speed are suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Figure D18. On-road speed profiles for standard-mobility and reference vehicles, West Germany, wet condition

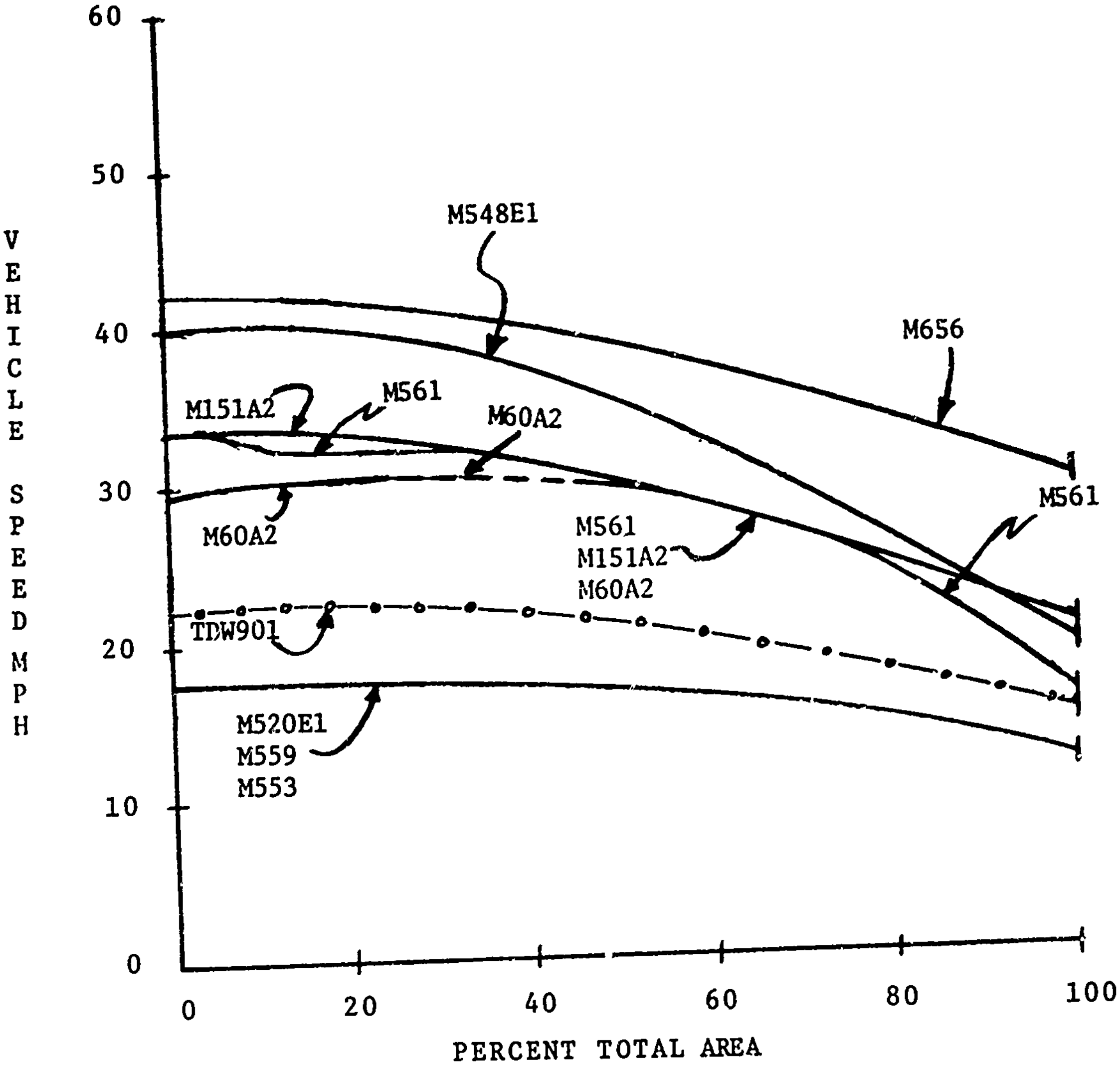
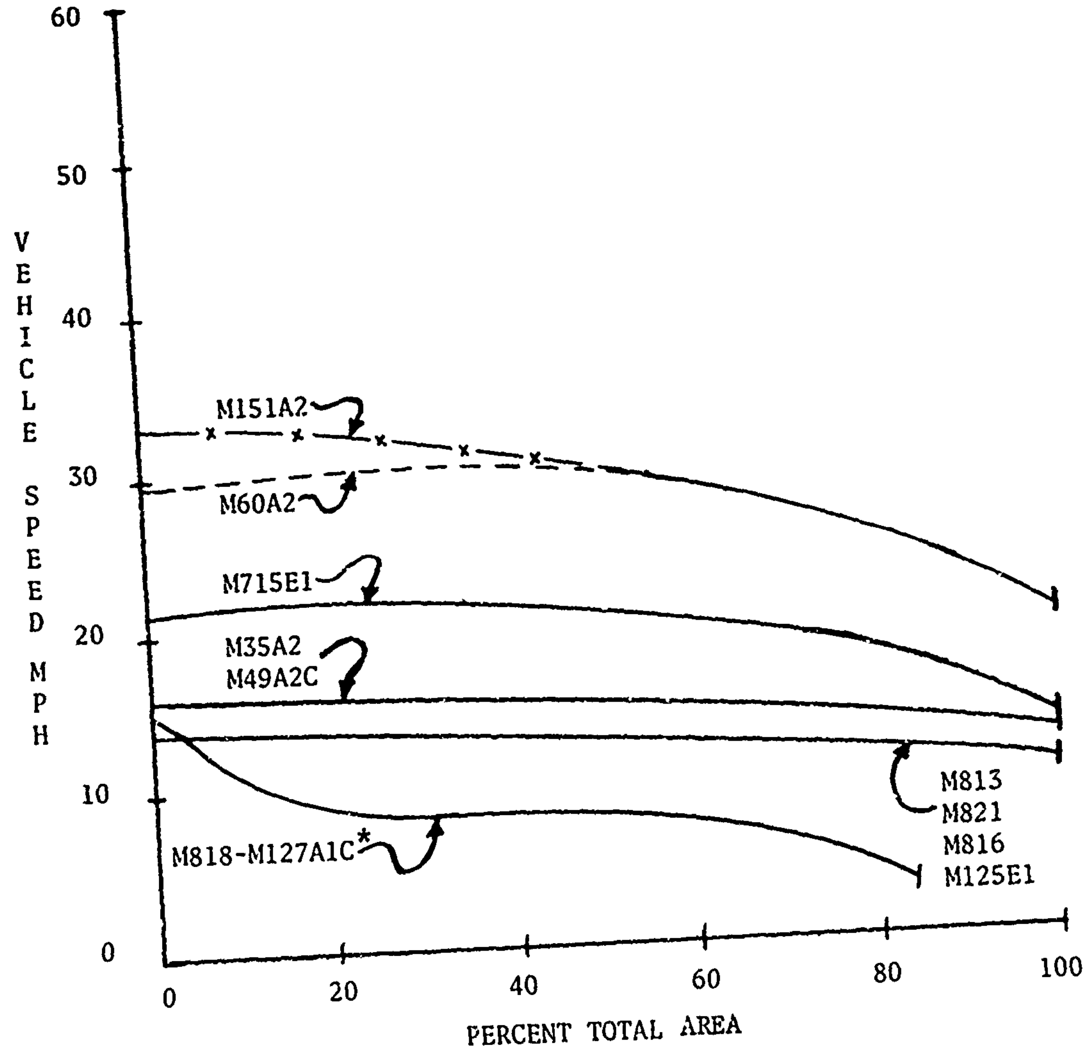


Figure D19. On-road speed profiles for high-mobility and reference vehicles, West Germany, snow condition



* Speeds in conditions approaching the final GO speed are suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Figure D20. On-road speed profile for standard-mobility and reference vehicles, West Germany, snow condition

TDW901 is also greater, because on road the greater power per ton of the M656 is not so often negated by its somewhat poorer ride dynamics.

Reasons for NOGO's or speed limits, off road

40. Concurrent with the assembly of the speed profiles, the data were analyzed to obtain diagnostic statistics that show the relative occurrence of reasons for NOGO's and of factors limiting speeds in GO situations. Tables D14-D16 summarize these results for the study vehicles in the same sample of the areal terrain in the Mid-East for which the speed profiles just discussed were made. Tables D17-D19 present the same data for the West Germany study area sample. These diagnostic data characterize the two areas in terms of the type of mobility problems posed as well as indicate for specific vehicles the design areas in which changes might benefit performance.

41. The diagnostics for the Mid-East study area in the (nonsand) wet and dry conditions show that NOGO situations in the areal terrain are primarily associated with the rocks and boulders that are prevalent throughout the area and that the smaller vehicles were hardest hit. Even when the obstacles were negotiable, they imposed speed limits for much of the time. Consistent with the prevalence of minor obstacles, terrain roughness is a major speed-limiting factor, especially in dry conditions. In the wet-surface condition, the weaker soils shift some of these limits to power limits, and in other situations, soil slipperiness effects on braking reduce speeds below the ride-speed level.

42. When the Mid-East area is converted to an all-sand-dune terrain, a large portion of the area becomes untrafficable for all of the wheeled vehicles. (If properly tired for operation in this type of terrain, NOGO's for such vehicles as the M656, M35A2, and M813 would drop to about the 13-14 percent level experienced by the GOER's and the TDW901.) The tracked vehicles, M60A2 and M548E1, had no trafficability problems per se, but both tracked and wheeled vehicles were more frequently power-limited in the sand condition than in either the wet or dry conditions.

43. Characteristics of the diagnostics for the wet and dry conditions over the selected topographic map sheet in the West Germany

Table D13

Relative V_x* for Selected Study Vehicles

	$V_{x,A}/V_{x,B}$ percent					
	Mid-East			West Germany		
Vehicles	Dry	Wet	Sand	Dry	Wet	Snow
1-1/4-ton trucks M651/M715E1	132	131	123	113	111	99
5-ton trucks M656/M813	87	97	100	95	96	176
8-ton trucks TDW901/M520E1	143	155	130	119	120	128
HIMO (5-ton vs 8-ton) M656/TDW901	114	115	124	122	121	116

* V_x on-road speed over x percent of MSR road-trail-traverse network, where x is the percentage that includes the 10 percent of trails and off-road traverses intrinsic to the as is network that are least difficult:

For Mid-East, x = 51

For West Germany, x - 87 (Appendix E).

Table D14

Reasons for Off-Road Nogo's or Speed Limits

Mid-East, Dry

Vehicles	Limiting Factors						
	NOGO		GO				
	Traction	Obstacles/Veg	Ride	Power	Visibility/ Braking	Obstacles/Veg	Urban Areas
M561	0.0	16.3	48.3	1.0	2.1	28.9	3.4
M656	0.0	12.7	46.3	4.9	4.2	28.5	3.4
M520E1	0.0	1.4	50.4	5.2	0.0	39.6	3.4
M559	0.0	1.4	47.2	5.9	0.0	42.1	3.4
M553	0.0	1.4	49.8	5.9	0.0	39.5	3.4
M548E1	0.0	11.1	45.9	5.3	0.1	34.2	3.4
M151A2	0.0	20.8	60.4	0.1	5.2	10.0	3.4
M715E1	0.0	17.8	55.4	0.1	0.0	23.4	3.4
M35A2	0.0	14.2	48.6	2.5	4.9	26.4	3.4
M49A2C	0.0	14.2	48.6	2.5	4.9	26.4	3.4
M813	0.0	12.1	49.2	1.6	2.3	28.4	3.4
M821	0.0	11.3	32.4	15.1	5.1	32.6	3.4
M816	0.0	12.5	44.7	10.4	2.1	26.8	3.4
M125E1	0.0	9.7	39.9	9.9	2.1	34.9	3.4
M818-M127A1C*	0.0	4.6	45.0	11.6	0.0	35.3	3.4
TDW901	0.0	2.4	36.2	17.7	5.0	35.3	3.4
M60A2	0.0	0.0	12.4	32.4	6.5	45.1	3.4

* All values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D15

Reasons for Off-Road NOGO's or Speed Limits

Mid-East, Wet

Vehicles	Limiting Factors						
	NOGO		GO				
	Traction	Obstacles/Veg	Ride	Power	Visibility/ Braking	Obstacles/Veg	Urban Areas
M561	0.0	16.3	36.6	2.3	12.6	28.7	3.4
M656	0.0	12.7	29.7	8.6	18.1	27.5	3.4
M520E1	0.0	1.4	35.0	22.3	0.0	37.8	3.4
M559	0.0	1.4	34.3	13.6	0.0	41.2	3.4
M553	0.0	1.4	37.1	20.2	0.0	37.9	3.4
M548E1	0.2	12.3	24.6	11.4	16.7	31.4	3.4
M151A2	0.0	20.4	38.5	0.2	27.1	10.4	3.4
M715E1	0.0	17.8	54.1	1.1	0.2	23.4	3.4
M35A2	0.0	14.2	31.5	7.6	17.2	26.1	3.4
M49A2C	0.0	14.2	31.5	7.6	17.2	26.1	3.4
M813	0.0	10.9	29.9	10.9	15.4	29.4	3.4
M821	0.0	11.3	17.0	20.4	16.2	31.6	3.4
M816	0.0	13.5	20.8	28.7	8.2	25.3	3.4
M125E1	0.0	10.2	20.7	20.3	12.4	32.9	3.4
M818-M127A1C*	0.8	6.4	20.3	35.5	3.8	29.7	3.4
TDW901	0.0	2.2	14.7	21.4	23.6	34.7	3.4
M60A2	0.0	8.6	7.2	22.4	20.5	37.9	3.4

* All values suspect,because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D16

Reasons for Off-Road NOGO's or Speed Limits

Mid-East, Sand

Vehicles	Limiting Factors						
	NOGO		GO				
	Traction	Obstacles/Veg	Ride	Power	Visibility/ Braking	Obstacles/Veg	Urban Areas
M561	24.8	17.8	26.2	9.4	1.2	17.2	3.4
M656	30.7	14.3	14.2	23.4	2.4	11.6	3.4
M520E1	13.4	6.8	23.6	27.9	0.0	25.0	3.4
M559	13.4	6.8	18.5	32.6	0.0	25.3	3.4
M553	13.4	6.8	19.6	34.0	0.0	22.9	3.4
M548E1	0.0	11.8	32.4	22.0	1.1	29.3	3.4
M151A2	40.9	22.9	26.3	4.7	1.1	0.8	3.4
M715E1	28.4	19.0	34.4	2.2	0.4	12.2	3.4
M35A2	52.2	18.8	11.7	8.0	0.9	5.0	3.4
M49A2C	52.2	18.8	11.7	8.0	0.9	5.0	3.4
M813	43.4	19.5	10.8	14.5	0.4	7.9	3.4
M821	68.7	13.6	0.0	11.0	0.4	2.9	3.4
M816	35.2	19.0	11.7	22.6	1.8	6.2	3.4
M125E1	61.8	15.7	1.6	12.2	0.4	4.3	3.4
M818-M127A1C*	72.8	8.4	1.7	11.8	0.2	1.5	3.4
TDW901	14.2	10.7	7.4	46.4	3.3	14.6	3.4
M60A2	0.0	0.0	7.9	41.4	4.5	42.7	3.4

* All values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D17

Reasons for Off-Road NOGO's or Speed Limits

West Germany, Dry

Vehicles	Limiting Factors						
	NOGO		GO				
	Traction	Obstacles/Veg	Ride	Power	Visibility / Braking	Obstacles/Veg	Urban Areas
M561	0.0	9.2	22.7	4.6	2.0	52.0	9.5
M656	0.0	8.2	19.3	11.1	3.8	48.1	9.5
M520E1	0.0	2.3	21.0	15.7	1.0	50.4	9.5
M559	0.0	2.0	19.9	19.3	0.9	48.4	9.5
M553	0.0	2.0	20.0	19.5	1.0	48.0	9.5
M548E1	0.0	9.9	17.8	13.2	3.4	46.2	9.5
M151A2	0.0	15.9	18.6	4.0	10.6	41.4	9.5
M715E1	0.0	9.1	26.1	1.2	2.2	51.9	9.5
M35A2	0.0	8.3	23.9	13.0	3.7	41.6	9.5
M49A2C	0.0	8.3	23.9	13.0	3.7	41.6	9.5
M813	0.0	7.7	19.7	11.0	4.5	47.8	9.5
M821	0.0	8.1	9.5	25.1	6.5	41.2	9.5
M816	0.0	8.2	16.6	21.6	3.2	40.9	9.5
M125E1	0.0	6.5	15.8	23.6	3.2	41.5	9.5
M818-M127A1C *	0.0	7.7	19.9	20.9	0.9	40.9	9.5
TDW901	0.0	4.9	15.4	26.9	5.9	37.4	9.5
M60A2	0.0	3.3	2.0	39.7	4.5	41.0	9.5

* All values suspect,because some NOGO's probably were not called Appendix A, paragraphs 14-17).

Table D18

Reasons for Off-Road NOGO's or Speed Limits

West Germany, Wet

Vehicles	Limiting Factors						
	NOGO		GO				
	Traction	Obstacles/Veg	Ride	Power	Visibility / Braking	Obstacles/Veg	Urban Areas
M561	0.0	9.2	12.8	7.3	10.8	50.4	9.5
M656	0.0	7.8	9.6	21.7	11.9	39.5	9.5
M520E1	0.8	2.4	11.4	39.0	1.9	34.8	9.5
M559	0.8	2.4	12.4	36.1	2.3	36.3	9.5
M553	0.8	2.5	12.2	36.9	2.4	35.5	9.5
M548E1	1.2	10.9	8.0	20.5	11.5	38.4	9.5
M151A2	0.0	13.4	10.6	2.5	24.0	39.9	9.5
M715E1	0.0	9.2	20.9	2.5	6.5	51.4	9.5
M35A2	0.0	8.3	12.2	19.8	13.7	36.5	9.5
M49A2C	0.0	8.3	12.2	19.8	13.7	36.5	9.5
M813	0.0	8.3	9.9	25.5	11.2	35.6	9.5
M821	0.0	8.1	4.4	30.5	10.8	36.7	9.5
M816	0.8	8.1	6.4	38.5	7.0	29.6	9.5
M125E1	0.6	7.4	7.0	34.8	7.3	33.4	9.5
M818-M127A1C *	3.4	7.5	9.3	41.3	2.9	25.8	9.5
TDW901	0.0	5.0	5.4	33.9	16.4	29.8	9.5
M60A2	0.8	5.7	0.4	29.7	14.3	39.6	9.5

* All values suspect, because some NOGO's probably were not called Appendix A, paragraphs 14-17).

Table D19

Reasons for Off-Road NOGO's or Speed Limits

West Germany, Snow

	Limiting Factors						
	NOGO		GO				
Vehicles	Traction	Obstacles/Veg	Ride	Power	Visibility / Braking	Obstacles/Veg	Urban Areas
M561	0.0	9.2	15.7	7.8	7.2	50.6	9.5
M656	0.0	7.8	13.3	21.8	7.2	40.4	9.5
M520E1	0.0	3.1	18.4	25.3	1.6	42.0	9.5
M559	0.0	3.1	18.0	26.8	1.5	41.0	9.5
M553	0.0	3.1	18.1	26.6	1.6	41.1	9.5
M548E1	0.0	9.9	17.5	5.1	8.6	49.4	9.5
M151A2	0.0	13.4	10.7	15.4	13.2	37.9	9.5
M715E1	0.0	9.2	17.2	15.5	2.9	45.7	9.5
M35A2	0.0	8.3	7.3	40.2	4.1	30.6	9.5
M49A2C	0.0	8.3	7.3	40.2	4.1	30.6	9.5
M813	0.0	8.2	5.6	46.1	3.2	27.5	9.5
M821	0.0	8.1	2.5	49.7	3.2	27.0	9.5
M816	0.0	8.3	2.9	53.6	2.7	23.0	9.5
M125E1	0.0	7.3	5.1	44.7	3.3	30.1	9.5
M818-M127A1C *	45.6	15.2	0.1	24.6	0.0	4.8	9.5
TDW901	0.0	5.0	7.9	34.2	9.2	34.2	9.5
M60A2	0.0	3.4	2.0	28.6	15.5	41.0	9.5

* All values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17)

study area are broadly similar to those for the same conditions in the Mid-East study area, except that the obstacles consist mainly of trees and forests rather than rocks and boulders. The GOER vehicles picked up some NOGO's due to traction failures (0.8 percent) but not as many as for the study area as a whole, as indicated earlier by the link performance statistics. (Over the map sheet characterized as having the most weak soil areas, this figure becomes 33.7 percent.)

44. When the same map sheet in the West Germany area is considered to be covered with 10 in. of dry snow and the ground beneath frozen, the diagnostics indicate that the problems are similar to those under wet conditions. The M818-M127A1C semitrailer rig with two heavy, unpowered axles is largely immobile, however, due to traction problems per se and vegetation override NOGO's resulting from insufficient traction.

45. In examining the diagnostics from the vehicle design or deficiency viewpoint, it is well to note that the diagnostic reasons always add to 100 percent. Conversions from NOGO- to GO-speed reasons are clearly significant gains, but substantial changes among GO reasons do not necessarily produce significant gains in overall speed. For example, a major change in vehicle suspension characteristics (alone) might well greatly reduce the occurrence of ride-speed limits for the vehicle, but the reduction will be distributed as increases among other reasons, whose associated speed limits might be only marginally higher than the ride-speed limits they replace.

Reasons for NOGO's or speed limits, on-road

46. Diagnostics for study vehicle operations on the roads, trails, and traverses of the complete as-is MSR network in the selected sample subareas of the two study areas are given in Tables D20-D25.

47. The roads and trails of the Mid-East area when traveled at maximum feasible speed consistently tax the power of the vehicle and the braking capacity of the road surfaces, generally limiting speeds to less than the 6-watt ride-speed limit. When the Mid-East area is converted to an all-sand-dune terrain, the resulting sand trails place severe limits on all of the wheeled study vehicles, in terms of both NOGO's and additional power requirements. The GOER vehicles (M520E1, M559, and

Table D20

Reasons for On-Road NOGO's or Speed Limits

Mid-East, Dry

Vehicles	Limiting Factors					
	NOGO	GO				
	Traction	Ride	Power	Visibility/Braking	Road Curvature	Urban Areas
M561	0.0	78.1	9.3	0	8.6	4.0
M656	0.0	75.2	9.7	0	11.1	4.0
M520E1	0.0	74.9	17.6	0	3.5	4.0
M559	0.0	73.2	19.6	0	3.3	4.0
M553	0.0	73.2	19.6	0	3.3	4.0
M548E1	0.0	73.1	15.1	0	7.8	4.0
M151A2	0.0	82.2	1.8	0	12.0	4.0
M715E1	0.0	84.0	1.6	0	10.4	4.0
M35A2	0.0	71.9	9.5	0	14.6	4.0
M49A2C	0.0	71.9	9.5	0	14.6	4.0
M813	0.0	60.2	21.6	0	14.1	4.0
M821	0.0	47.1	36.1	0	12.8	4.0
M816	0.0	49.5	34.5	0	12.0	4.0
M125E1	0.0	48.6	36.8	0	10.6	4.0
M818-M127A1C*	0.0	58.2	31.3	0	6.5	4.0
TDW901	0.0	53.0	33.9	0	9.1	4.0
M60A2	0.0	28.1	57.4	0	10.5	4.0

* All values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D21

Reasons for On-Road NOGO's or Speed Limits

Mid East, Wet

Vehicles	Limiting Factors					
	NOGO	GO				
	Traction	Ride	Power	Visibility/ Braking	Road Curvature	Urban Areas
M561	0.0	75.8	6.5	0.1	13.7	4.0
M656	0.0	66.0	19.2	0 1	10.7	4.0
M520E1	0.0	55.1	37.7	0	3.1	4.0
M559	0.0	55.1	37.9	0	3.0	4.0
M553	0.0	55.1	37.9	0	3.0	4.0
M548E1	0.1	69.4	18.6	0.3	7.6	4.0
M151A2	0.0	77.0	2.3	0.4	16.3	4.0
M715E1	0.0	82.6	3.0	0.1	10.3	4.0
M35A2	0.0	64.3	16.7	0.1	14.9	4.0
M49A2C	0.0	64.3	16.7	0.1	14.9	4.0
M813	0.0	46.1	37.8	0.6	11.5	4.0
M821	0.0	34.7	50.5	0.9	10.0	4.0
M816	0.0	35.9	51.2	0.3	8.7	4.0
M125E1	0.0	35.5	52.2	0.5	7.8	4.0
M818-M127A1C*	5.6	37.2	48.2	0.3	4.7	4.0
TDW901	0.0	43.6	42.8	0.2	9.3	4.0
M60A2	0.1	23.7	62.7	0.9	8.7	4.0

* All values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D22

Reasons for On-Road NOGO's or Speed Limits

Mid-East, Sand

Vehicles	Limiting Factors					
	NOGO	GO				
	Traction	Ride	Power	Visibility / Braking	Road Curvature	Urban Areas
M561	15.7	54.5	13.2	0.2	12.4	4.0
M656	21.3	40.2	26.9	0.1	7.6	4.0
M520E1	11.4	39.8	42.4	0	2.5	4.0
M559	11.4	39.8	42.5	0	2.4	4.0
M553	11.4	39.8	42.5	0	2.4	4.0
M548E1	0.0	54.4	34.6	0	7.0	4.0
M151A2	25.1	49.7	7.2	0.5	13.5	4.0
M715E1	21.3	62.2	3.0	0.1	9.5	4.0
M35A2	38.1	29.6	17.1	0.1	11.1	4.0
M49A2C	38.1	29.6	17.1	0.1	11.1	4.0
M813	25.1	22.6	38.0	2.0	8.4	4.0
M821	49.5	3.9	37.7	0	4.9	4.0
M816	25.1	12.8	51.5	0.2	6.3	4.0
M125E1	49.5	5.3	37.1	0	4.1	4.0
M818-M127A1C*	49.5	7.7	35.7	0	3.1	4.0
TDW901	11.4	14.5	64.0	0.4	5.8	4.0
M60A2	0.0	15.0	73.0	0	8.0	4.0

* All values suspect,because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D23

Reasons for On-Road NOGO's or Speed Limits

West Germany, Dry

Vehicles	Limiting Factors: NOGO: Traction	GO: Ride	GO: Power	GO: Visibility / Braking	GO: Road Curvature	GO: Urban Areas
M561	0.0	31.5	39.7	0.1	19.1	9.5
M656	0.0	48.9	22.4	0.0	19.2	9.5
M520E1	0.0	31.9	47.8	0.0	10.7	9.5
M559	0.0	31.5	48.7	0.0	10.3	9.5
M553	0.0	31.5	48.7	0.0	10.3	9.5
M548E1	0.0	31.1	42.3	0.0	17.1	9.5
M151A2	0.0	56.7	11.6	0.2	21.9	9.5
M715E1	0.0	38.8	19.5	0.2	32.0	9.5
M35A2	0.0	29.1	27.7	0.2	33.5	9.5
M49A2C	0.0	29.1	27.7	0.2	33.5	9.5
M813	0.0	11.3	59.0	0.0	20.1	9.5
M821	0.0	9.1	63.2	0.0	18.2	9.5
M816	0.0	9.6	62.6	0.0	18.2	9.5
M125E1	0.0	9.7	63.8	0.0	16.9	9.5
M818/M127A1C *	0.0	23.3	52.7	0.0	14.5	9.5
TDW901	0.0	14.7	60.8	0.1	14.9	9.5
M60A2	0.0	6.1	69.9	0.0	14.4	9.5

* All values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D24

Reasons for On-Road NOGO's or Speed Limits

West Germany, Wet

Vehicles	Limiting Factors					
	NOGO	GO				
	Traction	Ride	Power	Visibility/ Braking	Road Curvature	Urban Areas
M561	0.0	30.2	24.3	0.3	35.7	9.5
M656	0.0	47.6	23.1	0.0	19.8	9.5
M520E1	0.2	28.3	50.5	0.0	11.5	9.5
M559	0.2	28.2	50.8	0.0	11.2	9.5
M553	0.2	28.2	50.8	0.0	11.2	9.5
M548E1	0.0	30.0	42.7	0.0	17.8	9.5
M151A2	0.0	40.1	5.5	5.4	39.5	9.5
M715E1	0.0	38.7	17.7	2.0	32.1	9.5
M35A2	0.0	26.8	28.9	0.3	34.5	9.5
M49A2C	0.0	26.8	28.9	0.3	34.5	9.5
M813	0.0	9.0	60.2	0.5	20.7	9.5
M821	0.0	7.0	64.4	0.5	18.6	9.5
M816	0.2	7.2	64.4	0.5	18.3	9.5
M125E1	0.2	7.4	65.9	0.0	16.9	9.5
M818-M127A1C*	0.4	19.5	55.9	0.3	14.3	9.5
TDW901	0.0	12.8	56.4	0.3	21.0	9.5
M60A2	0.0	5.1	69.5	0.1	15.8	9.5

* All values suspect,because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D25

Reasons for On-Road NOGO's or Speed Limits

West Germany, Snow

Vehicles	Limiting Factors: NOGO — Traction	GO — Ride	GO — Power	GO — Visibility/ Braking	GO — Road Curvature	GO — Urban Areas
M561	0.0	19.3	45.8	2.2	23.2	9.5
M656	0.0	15.8	50.3	2.0	22.3	9.5
M520E1	0.0	16.7	63.1	0.0	10.6	9.5
M559	0.0	15.8	64.5	0.0	10.1	9.5
M553	0.0	15.8	64.5	0.0	10.1	9.5
M548E1	0.0	33.2	36.1	0.3	20.9	9.5
M151A2	0.0	16.0	49.7	1.5	23.2	9.5
M715E1	0.0	17.7	59.2	0.3	13.3	9.5
M35A2	0.0	4.5	76.3	0.4	9.3	95
M49A2C	0.0	4.5	76.3	0.4	9.3	9.5
M813	0.0	4.6	78.4	0.5	6.9	9.5
M821	0.0	3.4	80.7	0.5	5.9	9.5
M816	0.0	3.2	82.0	0.5	4.8	9.5
M125E1	0.0	4.6	77.4	0.5	7.9	9.5
M818/M127A1C *	21.8	0.7	67.6	0.0	0.4	9.5
TDW901	0.0	7.2	56.8	2.3	24.2	9.5
M60A2	0.0	7.0	63.7	0.0	19.8	9.5

* All vehicles suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

M553), the TDW901, and the M561, all on tires suitable for the terrain, encounter substantially fewer NOGO situations on the sand trails and off-road traverses in the network sample than do the remaining wheeled vehicles.

48. On the roads and trails of the West Germany area network sample, power demands are relatively less, and those vehicles with sufficient power reach ride-speed limits relatively often. As a result of the generally higher speeds and perhaps more road curvature, as compared to the Mid-East area, slowing for road curvature occurs more often as a speed-limiting factor.

49. Traction NOGO's occur for the M818-M127A1C tractor-trailer combination in the wet season in the Mid-East area and even more seriously in the West Germany area snow condition. These are attributable to the heavily loaded, unpowered axles of the trailer. A minor number of traction NOGO's on trails are also called for the all-wheel-drive GOER's, the M816 5-ton wrecker, and the 10-ton M125E1 cargo truck.

Job Statistics

50. In each study area, one-way travel time and distance for each study vehicle on each travel job defined in the scenario play were computed over three routes under three conditions. The speed data were forwarded to GRC for use in the TVFS simulations. Three types of jobs were included in the total set of predictions: logistic jobs, unit moves in the attack, and unit moves in delay operations. Average job performance of each vehicle was examined by considering that each vehicle did each job once. The resulting averages introduce some elements of mission requirements, but they are not weighted for frequency of job occurrence or the relative likelihood of any given vehicle type being employed. Such final weighting must be done by the TVFS simulations. Table D26 is a sample of the total output of the job statistics routine. Table 4 in the main text and Tables D27-D31 were extracted from the full output.

51. Characteristics of the logistic, attack, and delay job routes

Table D26

Sample Job Statistics Output

VEH #	AVG TIME	AVG SPEED	LINEAR FEATURES-ALL #	LINEAR FEATURES-ALL %	LINEAR FEATURES-ALL MEAN X-T	LINEAR FEATURES-ALL SD	LINEAR FEATURES-ALL % T-X	LINEAR FEATURES-ALL %TOT T-X	LINEAR FEATURES>30 #	LINEAR FEATURES>30 %	LINEAR FEATURES>30 MEAN X-T	LINEAR FEATURES>30 SD	LINEAR FEATURES>30 % T-X	NO-GO #	NO-GO %	NO-GO % DIST	NO-GO % TIME	NO-GO %TOT DIST	NO-GO %TOT TIME	TOT GO-T
**ROUTE PRIMARY			CONDITION WET		434 SAMPLES			7606.8 MILES**												
1	41.1	25.6	0	0	0	0	0	0	0	0	0	0	0	11	2.5	0.6	47.7	0.0	3.3	17241.6
2	42.8	24.5	0	0	0	0	0	0	0	0	0	0	0	11	2.5	0.6	47.1	0.0	3.2	18002.4
3	68.3	15.4	0	0	0	0	0	0	0	0	0	0	0	58	13.4	3.1	33.3	0.5	11.0	23440.6
4	69.3	15.2	0	0	0	0	0	0	0	0	0	0	0	58	13.4	3.1	32.9	0.5	10.8	23935.2
5	69.3	15.2	0	0	0	0	0	0	0	0	0	0	0	58	13.4	3.1	32.9	0.5	10.8	23960.2
6	47.5	22.1	0	0	0	0	0	0	0	0	0	0	0	25	5.8	0.9	41.1	0.1	6.7	18911.2
7	39.8	26.0	0	0	0	0	0	0	0	0	0	0	0	11	2.5	0.6	49.3	0.0	3.5	16393.9
8	43.5	24.2	0	0	0	0	0	0	0	0	0	0	0	15	3.5	1.0	41.9	0.0	4.4	17839.5
9	41.1	25.6	0	0	0	0	0	0	0	0	0	0	0	14	3.2	0.6	48.5	0.0	4.3	17074.3
10	41.1	25.6	0	0	0	0	0	0	0	0	0	0	0	14	3.2	0.6	[illegible].5	0.0	4.3	17074.3
11	44.1	23.9	0	0	0	0	0	0	0	0	0	0	0	15	3.5	1.2	36.2	0.1	4.4	17866.5
12	46.0	22.9	0	0	0	0	0	0	0	0	0	0	0	14	3.2	0.6	44.9	0.0	3.9	19198.0
13	57.2	18.4	0	0	0	0	0	0	0	0	0	0	0	58	13.4	3.1	36.0	0.5	13.1	18732.6
14	59.5	17.7	0	0	0	0	0	0	0	0	0	0	0	58	13.4	3.1	35.5	0.5	12.6	19724.3
15	66.4	15.8	0	0	0	0	0	0	0	0	0	0	0	64	14.7	3.2	34.5	0.5	12.5	22237.7
16	49.6	21.2	0	0	0	0	0	0	0	0	0	0	0	8	1.8	0.7	44.4	0.0	2.2	21043.1
17	52.3	20.1	0	0	0	0	0	0	0	0	0	0	0	22	5.1	1.0	41.5	0.1	5.6	21173.7
**ROUTE SECONDARY			CONDITION WET		434 SAMPLES			8741.5 MILES**												
1	52.5	23.0	0	0	0	0	0	0	0	0	0	0	0	12	2.8	0.8	36.1	0.0	2.0	22330.0
2	53.2	22.7	0	0	0	0	0	0	0	0	0	0	0	12	2.8	0.8	37.0	0.0	1.5	22626.6
3	99.7	12.1	0	0	0	0	0	0	0	0	0	0	0	111	25.6	3.2	26.9	0.9	13.9	29872.7
4	101.4	11.9	0	0	0	0	0	0	0	0	0	0	0	111	25.6	3.2	26.6	0.9	13.7	30577.1
5	101.5	11.9	0	0	0	0	0	0	0	0	0	0	0	111	25.6	3.2	26.6	0.9	13.6	30615.5
6	65.1	19.2	0	0	0	0	0	0	0	0	0	0	0	39	9.0	1.9	35.7	0.2	8.4	23453.4
7	49.3	24.5	0	0	0	0	0	0	0	0	0	0	0	12	2.8	0.8	38.5	0.0	2.1	20036.9
8	57.7	20.9	0	0	0	0	0	0	0	0	0	0	0	20	4.6	1.0	34.2	0.1	3.5	23916.4
9	51.2	23.6	0	0	0	0	0	0	0	0	0	0	0	18	4.1	0.7	35.7	0.0	3.0	21485.6
10	51.2	23.6	0	0	0	0	0	0	0	0	0	0	0	16	4.1	0.7	35.7	0.0	3.0	21485.6
11	56.4	21.4	0	0	0	0	0	0	0	0	0	0	0	23	5.3	1.2	29.2	0.1	4.2	22519.1
12	58.2	20.8	0	0	0	0	0	0	0	0	0	0	0	18	4.1	0.7	31.7	0.0	2.6	24518.9
13	85.7	14.1	0	0	0	0	0	0	0	0	0	0	0	111	25.6	3.2	29.2	0.9	16.2	23757.6
14	87.4	13.8	0	0	0	0	0	0	0	0	0	0	0	111	25.6	3.2	29.0	0.9	15.8	24528.1
15	101.2	11.9	0	0	0	0	0	0	0	0	0	0	0	119	27.4	3.6	27.5	1.1	15.0	28649.2
16	61.9	19.5	0	0	0	0	0	0	0	0	0	0	0	10	2.3	0.9	30.4	0.0	1.2	26529.7
17	65.7	18.1	0	0	0	0	0	0	0	0	0	0	0	35	8.1	1.9	36.0	0.2	7.3	25642.9
**ROUTE TERTIARY			CONDITION WET		434 SAMPLES			7606.8 MILES**												
1	58.4	18.0	93	21.4	27.8	29.0	23.4	10.2	31	7.1	52.0	39.2	40.4	95	21.9	1.2	45.7	0.5	18.2	17641.2
2	58.8	17.9	93	21.4	29.4	31.9	30.3	10.7	31	7.1	53.2	43.4	43.3	78	18.0	1.2	44.6	0.2	15.8	18593.3
3	86.8	12.1	92	21.2	30.2	28.9	25.0	7.4	33	7.6	50.6	44.1	32.7	119	27.4	2.7	33.9	0.8	17.3	24701.9
4	87.8	12.0	92	21.2	30.3	28.5	24.7	7.3	32	7.4	51.1	54.3	33.4	116	26.7	2.7	33.2	0.8	16.8	25244.5
5	88.1	11.9	92	21.2	30.3	28.6	24.7	7.3	32	7.4	51.1	54.4	33.4	120	27.6	2.6	33.5	0.8	17.2	25212.2
6	65.2	16.1	93	21.4	14.0	22.0	15.0	4.6	14	3.2	54.5	31.9	41.8	123	28.3	1.3	46.7	0.4	23.2	19603.7
7	64.9	16.2	92	21.2	42.9	48.3	36.0	14.0	57	13.1	59.8	42.1	43.4	139	32.0	1.2	45.3	0.4	24.9	16750.6
8	62.3	17.0	93	21.4	31.3	34.5	30.3	10.7	37	8.5	53.9	40.5	41.3	102	23.5	1.3	44.4	0.3	19.6	18332.8
9	57.1	18.4	93	21.4	29.9	32.6	31.6	11.2	34	7.8	52.4	43.0	44.5	80	18.4	1.2	45.6	0.2	16.7	17607.6
10	57.1	18.4	93	21.4	29.9	32.6	31.6	11.2	34	7.8	52.4	43.0	44.5	80	18.4	1.2	45.6	0.2	16.7	17607.6
11	61.3	17.2	92	21.2	30.6	32.5	30.1	10.6	37	8.5	50.1	52.2	40.1	82	18.9	1.4	43.0	0.3	16.4	18822.2
12	62.7	16.8	92	21.2	28.4	27.5	28.0	9.6	27	6.2	53.2	37.3	40.4	78	18.0	1.2	43.8	0.2	15.1	20246.5
13	78.4	13.4	92	21.2	32.3	33.4	27.8	8.7	36	8.3	52.2	46.1	36.9	140	32.3	2.5	38.0	0.9	22.6	19474.6
14	80.2	13.1	92	21.2	34.7	43.2	28.7	9.2	42	9.7	59.5	29.9	41.0	135	31.1	2.3	37.1	0.8	21.2	20630.4
15	91.1	11.5	92	21.2	41.6	47.4	29.8	9.7	57	13.1	57.2	43.6	35.9	150	34.6	2.8	35.7	1.0	21.2	23126.1
16	65.5	16.1	93	21.4	43.2	55.1	39.2	14.1	58	13.4	59.8	46.9	46.5	47	10.8	1.1	38.5	0.1	8.8	21858.3
17	66.0	15.9	92	21.2	18.4	25.8	18.7	5.9	26	6.0	52.9	29.5	40.7	76	18.0	1.3	41.4	0.3	14.6	22080.2

Table D27

Some Characteristics of Job Routes

Study Area Route	Mid-East MSR*	Mid-East Secondary	West Germany MSR	West Germany Secondary
All Jobs				
Number of jobs	245	245	434	434
Total distance**	1921	2015	7607	8742
Average job distance (one-way), mi.	7.8	8.2	17.5	20.1
Resupply Jobs (Logistic)				
Number of jobs	182	182	343	343
Total distance	1444	1481	6387	7435
Average job distance (one-way), mi.	7.9	8.1	18.6	21.7
Unit Move Jobs (Attack)				
Number of jobs	39	39	51	51
Total distance	264	287	666	703
Average job distance (one-way), mi.	6.8	7.4	13.1	13.8
Unit Move Jobs (Delay)				
Number of jobs	24	24	40	40
Total distance	213	247	554	603
Average job distance (one-way), mi.	8.9	10.3	13.8	15.1

* Interdicted MSR job distances are the same as MSR distances.
** Each job considered only once.

Table D28

Characteristics of Job Performance Speeds
All Vehicles, All Jobs

Condition	Route	Job Speed Range Hi mph	Lo mph	Hi/Lo	V_{mean} mph	δ/V_{mean}	T_{RTE*}/T_{MSR}	V_{cond}/V_{dry}
		Mid-East (245 Jobs)						
Dry	MSR	21.1	3.1	6.8	13.3	0.25	-	-
	Secondary	19.4	2.4	8.1	9.7	0.3	1.44	-
	Tertiary**	19.3	2.5	7.7	10.3	0.31	1.29	-
Wet	MSR	18.8	3.0	6.3	11.8	0.22	-	0.89
	Secondary	14.7	2.3	6.4	8.5	0.22	1.46	0.88
	Tertiary	15.0	2.5	6.0	9.1	0.25	1.30	0.88
Sand	MSR	21.3	1.1	19.4	6.2	0.72	-	0.47
	Secondary	19.4	1.0	19.4	4.9	0.75	1.33	0.51
	Tertiary	17.6	1.1	16.0	4.7	0.70	1.32	0.46
		West Germany (434 Jobs)						
Dry	MSR	30.6	17.6	1.7	25.0	0.14	-	-
	Secondary	27.0	16.3	1.7	22.5	0.14	1.28	-
	Tertiary	22.3	14.4	1.6	19.4	0.08	1.29	-
Wet	MSR	27.2	9.9	2.8	21.2	0.20	-	0.85
	Secondary	24.8	8.2	3.0	18.4	0.26	1.33	0.82
	Tertiary	18.8	7.8	2.4	15.4	0.16	1.38	0.79
Snow	MSR	23.3	2.1	11.1	14.8	0.34	-	0.59
	Secondary	20.5	1.7	12.1	13.4	0.34	1.27	0.60
	Tertiary	17.7	1.9	9.3	11.9	0.30	1.24	0.61

* Average job time including difference in average job distances.
** MSR with last on-road or trail link made an off-road traverse.

Table D29

Average Speed (mph) for Logistic Jobs
Mid-East

Vehicle	Routes: Primary* Dry	Primary* Wet	Primary* Sand	Secondary** Dry	Secondary** Wet	Secondary** Sand	Tertiary* Dry	Tertiary* Wet	Tertiary* Sand	All Routes & Conditions
M561	11.1	10.9	7.3	7.8	7.7	5.1	7.9	7.7	4.6	7.8
M656	14.4	14.0	6.9	10.5	10.4	5.0	10.5	10.3	4.2	8.1
M520E1	15.3	14.6	11.0	12.0	11.3	8.0	12.3	11.8	7.5	11.0
M559	15.0	14.3	10.7	11.8	11.2	7.9	12.1	11.6	7.3	10.8
M553	15.0	14.3	10.7	11.8	11.2	7.9	12.1	11.6	7.3	10.8
M548E1	18.2	15.3	17.8	12.0	11.2	11.8	13.5	11.8	13.1	13.4
M151A2	10.5	10.2	5.9	7.7	7.2	4.7	6.4	5.9	3.6	6.2
M715E1	9.2	9.0	5.6	6.6	6.5	4.4	6.1	6.0	3.5	5.8
M35A2	14.4	14.0	5.0	10.1	9.9	4.2	10.0	9.7	3.2	7.0
M49A2C	14.4	14.0	5.0	10.1	9.9	4.2	10.0	9.7	3.2	7.0
M813	19.4	13.9	5.1	12.4	9.7	4.3	13.0	9.6	3.4	7.4
M821	18.3	17.3	4.8	12.1	11.5	4.0	13.1	12.6	3.0	7.3
M816	13.8	13.1	5.4	9.7	9.1	4.1	9.2	8.9	3.5	6.9
M125E1	17.9	18.7	5.4	11.8	12.3	4.6	13.8	14.2	3.3	8.0
M818-M127A1C†	12.4	9.0	2.9	10.0	7.6	2.5	9.6	7.2	2.2	4.8
TDW901	19.0	18.1	9.9	15.6	14.2	7.4	16.2	15.0	6.7	11.9
M60A2	21.1	14.5	21.2	19.4	12.2	19.4	18.0	11.0	17.6	16.3

* 182 jobs, average one-way distance 7.9 miles.
** 182 jobs, average one-way distance 8.1 miles.
† All values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D30

Average Speed (mph) for Tactical Attack Jobs
Mid-East

Vehicle	Routes: Primary* Dry	Primary* Wet	Primary* Sand	Secondary** Dry	Secondary** Wet	Secondary** Sand	Tertiary* Dry	Tertiary* Wet	Tertiary* Sand	All Routes & Conditions
M561	3.2	3.2	2.0	2.7	2.7	1.6	2.7	2.7	1.7	2.4
M656	7.8	7.6	2.3	4.8	4.7	1.5	6.2	6.0	1.9	3.4
M520E1	7.9	7.4	3.7	6.0	5.5	3.0	7.1	6.7	3.1	4.9
M559	7.8	7.4	3.6	5.9	5.5	2.9	7.0	6.6	3.1	4.8
M553	7.8	7.4	3.6	5.9	5.5	2.9	7.0	6.6	3.1	4.8
M548E1	8.7	7.5	8.2	5.6	4.6	5.3	7.2	6.2	6.6	6.4
M151A2	3.3	3.1	2.0	2.6	2.3	1.4	2.7	2.5	1.6	2.2
M715E1	3.1	3.0	2.0	2.4	2.4	1.4	2.5	2.5	1.6	2.2
M35A2	6.4	6.2	1.8	3.9	3.8	1.3	4.8	4.7	1.5	2.8
M49A2C	6.4	6.2	1.8	3.9	3.8	1.3	4.8	4.7	1.5	2.8
M813	8.4	6.5	2.0	5.3	3.8	1.3	6.5	5.0	1.6	3.0
M821	8.0	7.6	1.8	5.4	5.1	1.3	6.4	6.1	1.5	3.0
M816	6.7	6.2	2.0	3.9	3.6	1.4	5.0	4.7	1.7	2.9
M125E1	8.4	8.0	1.9	5.4	5.4	1.3	7.2	6.[illegible]	1.6	3.2
M818-M127A1C†	7.5	4.2	1.3	4.5	2.7	1.0	5.9	3.6	1.1	2.2
TDW901	12.7	9.5	3.2	8.5	6.1	2.4	10.0	7.6	2.7	4.3
M60A2	16.4	8.8	12.8	13.3	6.5	10.3	15.2	7.3	11.3	10.3

* 39 jobs, average one-way distance 6.8 miles.
** 39 jobs, average one-way distance 7.4 miles.
† All values suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D31

Average Speed (mph) for Tactical Delay Jobs

Mid-East

	Routes									
	Primary*			Secondary**			Tertiary*			All Routes
Vehicle	Dry	Wet	Sand	Dry	Wet	Sand	Dry	Wet	Sand	& Conditions
M561	14.9	13.2	7.6	9.8	8.9	7.0	12.3	11.0	5.4	9.1
M656	19.2	18.8	6.9	15.0	14.7	6.9	14.8	14.5	4.6	10.2
M520E1	12.1	11.8	8.4	9.4	8.9	7.5	10.2	9.9	6.9	9.2
M559	11.9	11.6	8.2	9.3	8.8	7.4	10.0	9.8	6.7	9.0
M553	11.9	11.6	8.2	9.3	8.8	7.4	10.0	9.8	6.7	9.0
M548E1	19.0	14.6	18.5	13.8	11.4	13.7	14.7	11.9	14.3	14.3
M151A2	11.2	9.0	5.2	9.0	6.7	5.6	8.4	6.7	3.6	6.5
M715E1	7.6	7.0	4.8	6.8	6.2	5.1	6.2	5.8	3.5	5.6
M35A2	20.6	17.2	4.7	15.9	13.7	5.3	15.4	13.4	3.3	8.3
M49A2C	20.6	17.2	4.7	15.9	13.7	5.3	15.4	13.4	3.3	8.3
M813	16.9	16.4	4.4	13.2	12.7	4.9	13.0	12.7	3.2	7.7
M821	17.6	16.8	4.0	13.9	12.9	4.3	13.6	13.1	2.6	7.0
M816	16.2	15.4	4.7	12.8	11.4	4.7	12.6	12.1	3.4	7.7
M125E1	16.8	16.1	4.4	13.3	12.2	5.0	13.1	12.7	3.0	7.5
M818-M127A1C†	15.4	12.8	2.9	12.4	10.0	3.1	13.5	10.9	2.3	5.7
TDW901	20.3	14.5	11.0	17.5	10.9	11.2	19.3	13.1	9.1	13.1
M60A2	17.6	8.2	17.1	15.7	9.2	15.8	16.4	6.7	15.7	12.0

* 24 jobs, average one-way distance 8.9 miles.

** 24 jobs, average one-way distance 10.3 miles.

† All values suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

and of all job routes in the two areas are summarized in Table 4 of the main text. Job routes in the West Germany study area are 2-2.5 times as long as those in the Mid-East study area. Distances involved in resupply and other mission distances are about the same in the Mid-East area, but the resupply missions are 35 to 55 percent longer in the West Germany area.

Average job speeds, all vehicles

52. Table D28 summarizes some characteristics of the average job performance speeds for all vehicles, each doing each job once. The figures are intended to give some perspective to the individual vehicle job performance figures that follow. For each area, condition, and route, Table D28 shows the range of average job speeds for all 17 study vehicles, the ratio of high to low values (Hi/Lo), the simple mean for all vehicles, and the associated standard deviation as a fraction of the mean (δ/V_{mean}). The next column shows the ratio of the time required for an average job on the secondary or tertiary routes (including the increased distance for the secondary route) in relation to the average job time on the MSR (T_{RTE}/T_{MSR}). The final column shows the ratio of mean speed on a given route under wet or special (sand or snow) conditions to the speed on the same route under dry conditions (V_{cond}/V_{dry}).

53. Although the job speed averages are not fully mission weighed, they do reflect the fact that the several individual job routes repeatedly involved travel over many of the same links associated with the better roads. As a result, in all cases except on the tertiary (partially interdicted MSR) routes in the West Germany study area in dry conditions, average job speeds in both areas are in excess of average as-is link speeds based on traveling each link only once. This effect is more pronounced in the Mid East study area probably because 18.1 percent of the as-is route network distance in that area is off road, whereas only 0.1 percent of the West Germany study area as-is network is off road. The relatively high average job speeds even on the tertiary routes indicate that the interdiction played, which on the average converted from on road (usually trails) to off road 8 percent of the job routes in the Mid-East stu^d area and 4 percent of those in the West Germany

study area, was not severe in terms of vehicle performance. Despite this, and the fact that absolute job speeds are higher than link speeds, the range in speed performance between the slowest and fastest vehicles, as reflected by the ratio of highest to lowest speeds in a given situation (Hi/Lo), remains significant.

54. As noted in paragraph 10 in each study area reductions in average speeds for all vehicles associated with changes in conditions were essentially the same percent for the links as-is and as off-road traverses. Consistent with this, relative changes in average job speeds with condition (V_{cond}/V_{dry}), though a function of study area and condition, is independent of the route class (MSR, secondary or tertiary). The ratio T_{RTE}/T_{MSR} is also remarkably consistent for a given nonMSR route across conditions within each study area. The secondary and tertiary routes conceptionally play MSR disruption; however, the implied degree of disruption is not the same. As a result, no significance can be placed on the fact that the increase in average job travel time over MSR travel time is very nearly the same for the other two routes.

55. The job speeds confirm that, as was indicated by the overall average link speeds (paragraph 11), the arbitrary sand and snow conditions in the Mid-East and West Germany study areas, respectively, are in each case the severest of the three conditions for each area.

Average job speeds, individual vehicles

56. Tables D29-D31 present the average individual vehicle job speeds in the two study areas, three conditions, three routes, for job routes characterized for 182 logistic missions, 39 attack moves, and 24 delay moves in the Mid-East study area. Tables D32-D34 present the corresponding data for 343 logistic, 51 attack, and 40 delay jobs in the West Germany study area. In general, speeds over the attack job routes in the Mid-East area are 3-6 mph slower than the logistic job averages, whereas delay job speeds are about the same (± 2 mph, depending on vehicle, route class, and conditions). In the West Germany area, attack job speeds are 1-2 mph less than logistic job speeds, and delay job speeds are 2-3 mph slower.

Table D32

Average Speed (mph) for Logistic Jobs
West Germany

	Routes									
	Primary*			Secondary**			Tertiary*			All Routes
Vehicle	Dry*	Wet	Snow	Dry	Wet	Snow	Dry	Wet	Snow	& Conditions
M561	28.9	26.0	20.7	25.2	23.3	18.7	20.9	18.2	15.5	21.2
M656	27.4	24.9	19.8	24.7	23.0	18.2	21.2	18.2	15.4	20.8
M520E1	20.5	16.3	14.3	18.2	12.7	13.4	17.8	12.7	12.2	14.9
M559	20.1	16.1	13.8	17.8	12.4	12.9	17.5	12.6	11.9	14.5
M553	20.1	16.0	13.8	17.7	12.4	12.9	17.4	12.5	11.9	14.5
M548E1	26.0	22.6	23.3	23.6	19.8	20.5	19.2	16.4	17.4	20.6
M151A2	30.6	27.2	20.4	27.0	24.8	17.1	18.8	16.5	13.8	20.4
M715E1	28.0	24.8	16.4	23.4	21.4	14.1	20.3	17.4	12.8	18.7
M35A2	29.2	26.0	13.3	26.4	24.0	12.0	22.3	18.8	11.2	18.1
M49A2C	29.2	26.0	13.3	26.4	24.0	12.0	22.3	18.8	11.2	18.1
M813	27.9	24.4	11.5	25.4	22.2	10.5	21.5	17.5	9.9	16.4
M821	25.9	23.3	10.1	23.2	21.1	9.2	20.3	17.1	8.8	15.0
M816	26.1	19.5	9.5	23.3	14.8	8.7	20.3	14.1	8.3	13.6
M125E1	24.6	18.7	11.7	22.4	14.5	10.6	20.1	13.9	9.9	14.8
M818-M127A1C	21.7	16.9	3.4	19.1	12.6	2.3	17.3†	12.3	3.1†	6.3
TDW901	23.3	21.6	17.2	21.0	19.7	16.0	19.9	16.4	13.8	18.3
M60A2	22.9	20.4	21.0	21.7	18.7	19.4	20.0	16.3	17.7	19.6

* 343 jobs, average one-way distance 18.6 miles.
** 343 jobs, average one-way distance 21.7 miles.
† Values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D33

Average Speed (mph) for Tactical Attack Jobs
West Germany

	Routes									
	Primary*			Secondary**			Tertiary*			All Routes
Vehicle	Dry*	Wet	Snow	Dry	Wet	Snow	Dry	Wet	Snow	& Conditions
M561	25.7	24.1	18.6	23.6	22.3	18.0	18.9	16.9	13.2	19.5
M656	24.7	23.4	17.9	23.2	21.9	17.5	18.3	16.2	13.4	18.9
M520E1	18.2	14.5	13.2	16.9	11.2	12.8	14.8	11.0	10.5	13.2
M559	17.7	14.2	12.7	16.5	11.0	12.4	14.4	10.7	10.4	12.9
M553	17.7	14.2	12.7	16.5	11.0	12.4	14.4	10.7	10.2	12.9
M548E1	23.6	21.5	20.6	22.2	17.7	19.3	17.1	15.5	15.4	18.8
M151A2	27.3	25.5	18.9	25.3	23.8	18.4	17.8	15.5	12.6	19.4
M715E1	23.9	21.8	15.6	21.8	20.7	15.1	17.7	15.1	11.8	17.3
M35A2	26.3	23.8	12.9	24.6	23.0	12.8	19.2	16.1	10.3	17.0
M49A2C	26.3	23.8	12.9	24.6	23.0	12.8	19.2	16.1	10.3	17.0
M813	25.4	22.2	11.2	23.8	21.6	11.1	18.7	15.6	9.2	15.6
M821	23.0	21.1	9.7	21.6	20.2	9.6	17.4	14.9	8.2	14.1
M816	23.2	17.5	9.2	21.6	13.0	9.1	17.4	12.4	7.7	12.7
M125E1	22.3	17.0	11.2	21.1	12.9	11.1	16.4	11.9	8.8	13.5
M818-M127A1C	18.9	13.8	2.1	17.6	10.2	1.7	14.5†	10.0†	1.9†	4.4
TDW901	20.8	19.8	15.9	19.7	16.7	15.3	16.2	13.9	12.1	16.4
M60A2	21.5	19.8	19.4	20.7	16.7	18.6	17.0	14.3	14.8	17.8

* 51 jobs, average one-way distance 13.1 miles.
** 51 jobs, average one-way distance 13.8 miles.
† Values suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D34

Average Speed (mph) for Tactical Delay Jobs
West Germany

Vehicle	Primary* Dry*	Primary* Wet	Primary* Snow	Secondary** Dry	Secondary** Wet	Secondary** Snow	Tertiary* Dry	Tertiary* Wet	Tertiary* Snow	All Routes & Conditions
M561	25.4	23.1	19.1	23.1	20.5	16.3	19.3	17.3	15.1	19.4
M656	24.6	22.4	18.5	23.3	20.7	16.2	19.0	16.9	14.7	19.1
M520E1	18.1	10.0	13.4	16.7	8.5	11.9	16.0	8.6	11.9	11.9
M559	17.7	9.9	13.0	16.3	8.4	11.6	15.7	8.5	11.5	11.7
M553	17.6	9.9	12.9	16.3	8.4	11.6	15.7	8.5	11.5	11.7
M548E1	23.4	18.6	20.8	22.2	14.6	19.6	18.0	13.7	16.2	18.0
M151A2	27.3	24.6	19.1	25.2	22.2	16.3	15.1	14.1	12.1	18.2
M715E1	24.2	20.5	15.5	21.5	16.9	13.5	18.3	15.3	12.5	16.8
M35A2	26.3	23.5	13.0	25.0	20.2	11.7	20.0	17.2	10.8	16.9
M49A2C	26.3	23.5	13.0	25.0	20.2	11.7	20.0	17.2	10.8	16.9
M813	25.2	20.6	11.2	23.9	15.1	10.2	19.9	15.2	9.5	14.9
M821	23.0	20.5	9.9	21.8	17.6	8.9	18.0	15.6	8.6	14.0
M816	23.1	11.3	9.3	21.8	9.5	8.4	18.0	9.0	8.1	11.3
M125E1	22.3	11.1	11.2	21.1	9.4	10.1	18.2	8.7	9.3	11.9
M818-M127A1C	19.0	10.2	2.2	17.7	8.2	1.7	15.0†	7.8†	2.0†	4.4
TDW901	20.9	19.3	16.1	20.1	18.0	15.5	17.7	15.6	13.5	17.1
M60A2	21.5	17.8	19.6	21.1	14.2	19.2	18.5	13.8	16.7	17.6

* 40 jobs, average one-way distance 13.8 miles.

** 40 jobs, average one-way distance 15.1 miles.

† Values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

57. The mass of the data in Tables D29-D34 tends to obscure the important observation that there are significant job speed performance differences among vehicles. Table D35 summarizes a number of direct comparisons in the two study areas in logistic, attack, and delay jobs. Ratios are shown of job speed of the 1-1/4 ton M561 as a percent of that for the 1-1/4-ton M715E1, 5-ton M656 versus 5-ton M813, 8-ton TDW901 versus 8-ton M520E1, and 5-ton M656 versus 8-ton TDW901. The range for the ratio over all route classes (MSR, secondary, and tertiary) and conditions is shown, along with the simple mean for all nine route class-condition combinations. The order of speeds for the baseline vehicles in each comparison is 10 mph (1.3-19.4) in the Mid-East study area and 18 mph (8.6-28.0) in the West Germany area.

58. The data show that, despite overall differences in speed levels on the logistic, attack, and delay jobs, the better vehicles in a given comparison are consistently better in the 27 individual job, route, and condition situations in which each comparison was made. As indicated by underlines in Table D35, there were a small number of instances where the vehicle of nominally higher mobility did not outperform its comparison vehicle. Examination of the full array of speed ratings from which Table D35 was extracted shows that in the Mid-East study area, the M813 outperformed the M656 in 6 of 27 comparisons (6 dry, 0 wet, 7 sand), all in dry condition; the M520E1 outperformed the TDW901 in 6 of 9 sand conditions on all routes; and the 5-ton M656 outperformed the 8-ton TDW901 in three of nine delay job route-condition situations. In the West Germany area, the M813 outperformed the M656 in 9 of 27 comparisons, all in the dry condition.

59. The mean job speed performance improvements between good and current best vehicles in each payload class, i.e. excepting the special M656-TDW901 comparisons, range from 3 to 68 percent and are of the order of 24 percent in the Mid-East study area and 21 percent in the West Germany study area. The M656 and TDW901 comparisons result in a virtual standoff when both study areas are considered. While the job mobility of the TDW901 is comparable to that of the M656 high-mobility truck, the TDW901 versus M520E1 (GOER) comparisons show that the job speed of the

Table D35

Comparative Job Speed Performance of

Selected Study Vehicles

All Routes, All Conditions

Vehicles	Ratio of Job Speeds, percent								
	Logistic Job			Attack Jobs			Delay Jobs		
	Hi	Lo	Mean	Hi	Lo	Mean	Hi	Lo	Mean
Mid-East									
1-1/4-ton trucks M561/M715E1	131	116	124	114	100	108	198	137	168
5-ton trucks M656/M813	135	74	103	124	91	110	157	114	125
8-ton trucks TDW901/M520E1	136	89	115	161	80	117	189	122	148
HIMO 5-ton vs 8-ton M656/TDW901	77	83	70	80	56	69	135	51	90
West Germany									
1-1/4-ton trucks M561/M715E1	133	103	113	120	107	112	123	101	114
5-ton trucks M656/M813	173	97	123	158	97	118	165	95	125
8-ton trucks TDW901/M520E1	155	112	123	167	79	121	212	111	144
HIMO 5-ton vs 8-ton M656/TDW901	118	107	114	119	111	116	118	105	112

GOER consistently falls short of that of M656. Again, blanket inclusion of the GOER vehicles (M520E1, M559, and M553) in the high-mobility fleet distorts the potential of modern high-mobility trucks.

NOGO's encountered on jobs

60. NOGO time assessments to average job travel times in the Mid-East study area accounted for approximately 20 percent of the total; in the West Germany study area, about 10 percent.

61. Tables D36-D38 show for each vehicle, route, and condition the percentages of logistic, attack, and delay jobs in the Mid-East study area in which some areal terrain or on-road NOGO situations were found. Tables D39-D41 give like information for jobs in the West Germany study area.

62. In the Mid-East area, all vehicles encountered some NOGO's on all routes and in all conditions, but both of the tracked vehicles, M60A2 and M548E1 were relatively untroubled. Among the wheeled vehicles, the GOER's (M520E1, M559, and M553) clearly had the least difficulties, generally matching the performance of the tracked vehicles. The TDW901 ranks just behind to the GOER's with less than 1.5 percent of all jobs involving NOGO problems. The overall values for the M561 and M656 are approximately 2 percent; for the remainder of the vehicles, 3 percent. NOGO's were involved in two to three times as many jobs in the all-sand-dune terrain condition.

63. In the West Germany study area, less than 0.4 percent of all jobs for all vehicles, conditions, and routes involve NOGO's. The most troublesome situation for all vehicles except the M818-M127A1C tractor-trailer was the tertiary route under wet conditions, but even in this situation a majority of the vehicles encountered NOGO's on no more than 1 percent of all jobs. The only serious NOGO problems were those of the M818-M127A1C tractor-trailer in the snow condition.

Job travel time spent in crossing linear features

64. Examination of the basic statistical output shows that (such as shown in Table D26) linear-feature-crossing times included in average job travel times in the Mid-East study generally account for less than 2 percent of total travel time. In the West Germany area, MSR and

Table D36

Percentages of Logistic Jobs Involving Some NOGO Situations

Mid-East

Vehicle	Routes: Primary* Dry	Primary* Wet	Primary* Sand	Secondary** Dry	Secondary** Wet	Secondary** Sand	Tertiary* Dry	Tertiary* Wet	Tertiary* Sand	All Routes & Conditions
M561	0.6	0.6	1.2	1.2	1.2	2.7	1.8	1.8	4.2	1.7
M656	0.4	0.4	1.4	0.7	0.7	2.8	1.2	1.2	4.8	1.5
M520E1	0.1	0.1	0.3	0.1	0.1	0.8	0.2	0.2	1.2	0.3
M559	0.1	0.1	0.3	0.1	0.1	0.8	0.2	0.2	1.2	0.3
M553	0.1	0.1	0.3	0.1	0.1	0.8	0.2	0.2	1.2	0.3
M548E1	0.2	0.2	0.2	0.5	0.6	0.5	0.7	0.8	0.7	0.5
M151A2	0.9	0.9	2.0	1.2	1.2	4.4	3.2	3.1	6.6	2.6
M715E1	0.8	0.8	1.7	1.4	1.4	3.2	2.5	2.5	6.1	2.3
M35A2	0.4	0.4	1.9	0.8	0.8	4.7	1.3	1.3	6.5	2.0
M49A2C	0.4	0.4	1.9	0.8	0.8	4.6	1.3	1.2	6.6	2.0
M813	0.1	0.4	1.9	0.5	0.8	4.4	0.7	1.2	6.2	1.8
M821	0.2	0.2	2.3	0.6	0.6	5.6	0.6	0.6	8.2	2.1
M816	0.4	0.4	1.5	0.8	0.8	3.1	1.2	1.2	5.2	1.6
M125E1	0.2	0.1	1.9	0.5	0.4	5.0	0.5	0.5	6.9	1.8
M818 M127A1C†	0.4	1.8	5.1	0.5	1.0	9.1	1.0	2.5	10.7	3.6
TDW901	0.1	0.1	0.4	0.2	0.2	1.0	0.3	0.3	1.5	0.5
M60A2	0.1	0.3	0.1	0.1	0.5	0.1	0.2	0.8	0.2	0.3

* 182 jobs, average one-way distance 7.9 miles.
** 182 jobs, average one-way distance 8.1 miles.
† All values suspect, because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D37

Percentages of Tactical Attack Jobs Involving Some NOGO Situations

Mid-East

Vehicle	Routes: Primary* Dry	Primary* Wet	Primary* Sand	Secondary** Dry	Secondary** Wet	Secondary** Sand	Tertiary* Dry	Tertiary* Wet	Tertiary* Sand	All Routes & Conditions
M561	4.8	4.8	10.6	5.8	5.8	18.6	6.1	6.1	13.3	8.4
M656	1.1	1.1	10.1	2.9	2.9	19.5	1.7	1.7	12.7	6.0
M520E1	0.4	0.4	4.2	0.6	0.6	5.1	0.4	0.4	5.0	1.9
M559	0.4	0.4	4.7	0.6	0.6	5.0	0.4	0.4	5.0	1.9
M553	0.4	0.4	4.2	0.6	0.6	5.0	0.4	0.4	5.0	1.9
M548E1	0.8	1.0	0.9	2.3	2.5	2.3	1.1	1.3	1.3	1.5
M151A2	4.8	4.8	11.9	6.2	6.1	26.0	6.5	6.4	15.8	9.8
M715E1	5.1	5.1	11.3	7.3	7.3	21.5	6.7	6.7	14.6	9.5
M35A2	1.4	1.4	13.7	3.6	3.6	29.4	2.4	2.4	18.2	8.5
M49A2C	1.4	1.4	13.6	3.6	3.6	28.6	2.4	2.4	17.6	8.3
M813	0.8	1.3	11.9	2.2	3.5	26.6	1.5	1.9	15.8	7.3
M821	1.2	1.2	15.8	3.0	3.0	32.9	1.6	1.6	20.7	9.0
M816	1.2	1.3	10.6	3.4	3.5	22.0	2.1	2.2	13.7	6.7
M125E1	0.8	0.8	14.6	2.1	2.0	30.6	1.0	1.0	19.1	8.0
M818-M127A1G†	0.6	4.6	21.7	2.0	5.8	38.2	1.3	5.5	26.1	11.8
TDW901	0.2	0.5	4.9	0.8	1.1	5.7	0.4	0.6	5.8	2.2
M60A2	0.2	0.7	0.3	0.8	1.5	0.2	0.4	0.9	0.3	0.6

* 39 jobs, average one-way distance 3.8 miles.
** 39 jobs, average one-way distance 7.4 miles.
† All values suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D38

Percentages of Tactical-Delay Jobs Involving Some NOGO Situations
Mid-East

Vehicles	Primary* Dry	Primary* Wet	Primary* Sand	Secondary** Dry	Secondary** Wet	Secondary** Sand	Tertiary* Dry	Tertiary* Wet	Tertiary* Sand	All Routes & Conditions
M561	0.4	0.4	1.3	0.5	0.5	1.2	0.9	0.9	2.8	1.0
M656	0.4	0.4	2.7	0.5	0.5	2.2	0.5	0.5	4.9	1.4
M520E1	0.4	0.4	0.8	0.5	0.5	0.6	0.2	0.2	1.2	0.5
M559	0.4	0.4	0.8	0.5	0.5	0.6	0.2	0.2	1.2	0.5
M553	0.4	0.4	0.8	0.5	0.5	0.6	0.2	0.2	1.2	0.5
M548E1	0.4	0.4	0.8	0.0†	0.4	0.0†	0.5	0.9	0.5	0.4
M151A2	1.2	1.2	4.6	1.0	1.0	4.3	2.0	2.0	7.3	2.7
M715E1	2.2	2.2	4.5	2.7	2.7	4.3	2.9	2.9	6.9	3.5
M35A2	2.2	2.2	4.7	2.7	2.7	4.3	0.5	0.5	7.8	3.1
M49A2C	2.2	2.2	4.6	2.7	2.7	4.3	0.5	0.5	7.8	3.1
M813	2.2	2.2	4.6	2.7	2.7	4.3	0.5	0.5	7.3	3.0
M821	2.2	2.2	6.7	2.7	2.7	6.9	0.5	0.5	11.3	4.0
M816	2.2	2.2	2.7	2.7	2.7	2.2	0.5	0.5	5.1	2.3
M125E1	2.2	2.2	5.1	2.7	2.7	4.6	0.5	0.5	8.4	3.2
M818-M127A1C†	2.2	0.4	6.7	2.7	0.4	6.4	0.2	0.7	10.3	3.3
TDW901	2.2	0.4	0.8	2.7	0.4	0.6	0.2	0.7	1.4	1.0
M60A2	2.2	1.8	0.8	2.7	2.1	0.6	0.2	2.4	1.4	1.6

* 24 jobs, average one-way distance 8.9 miles.
** 24 jobs, average one-way distance 10.3 miles.
† All values suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D39

Percentages of Logistic Jobs Involving Some NOGO Situations
West Germany

	Routes									
	Primary*			Secondary**			Tertiary*			All Routes
Vehicle	Dry	Wet	Snow	Dry	Wet	Snow	Dry	Wet	Snow	& Conditions
M561	0	0	0	0	0	0	0.2	0.3	0.3	0.1
M656	0	0	0	0	0	0	0.2	0.2	0.2	0.1
M520E1	0	0.4	0	0	0.9	0	0	0.8	0.1	0.2
M559	0	0.4	0	0	0.9	0	0	0.8	0.1	0.2
M553	0	0.4	0	0	0.9	0	0	0.8	0.1	0.2
M548E1	0	0.1	0	0	0.2	0	0.2	0.4	0.2	0.1
M151A2	0	0	0.1	0	0	0.2	0.4	0.4	0.5	0.2
M715E1	0	0	0.1	0	0	0.2	0.2	0.4	0.3	0.1
M35A2	0	0	0.1	0	0	0.2	0.2	0.2	0.3	0.1
M49A2C	0	0	0.1	0	0	0.2	0.2	0.2	0.3	0.1
M813	0	0.1	0.1	0	0.1	0.2	0.2	0.3	0.3	0.1
M821	0	0	0.1	0	0	0.2	0.2	0.2	0.3	0.1
M816	0	0.4	0.1	0	0.9	0.2	0.1	0.9	0.3	0.3
M125E1	0	0.4	0	0	0.9	0.1	0.1	0.7	0.2	0.3
M818-M127A1C	0	0.4	5.4	0	1.0	11.2	0.2†	1.0†	6.4†	2.8†
TDW901	0	0	0	0	0	0	0.1	0.1	0.1	0
M60A2	0	0.1	0	0	0.2	0	0.1	0.2	0.1	0.1

* 343 jobs, average one-way distance 18.6 miles.
** 343 jobs, average one-way distance 21.7 miles.
† Values suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

Table D40

Percentages of Tactical Attack Jobs Involving Some NOGO Situations

West Germany

Vehicle	Primary* Dry	Primary* Wet	Primary* Snow	Secondary** Dry	Secondary** Wet	Secondary** Snow	Tertiary* Dry	Tertiary* Wet	Tertiary* Snow	All Routes & Conditions
M561	0	0.1	0	0	0.1	0	0.1	0.3	0.3	0.1
M656	0	0.1	0	0	0.1	0	0.1	0.3	0.2	0.1
M520E1	0	0.2	0	0	0.7	0	0.1	0.5	0.2	0.2
M559	0	0.2	0	0	0.7	0	0.1	0.5	0.2	0.2
M553	0	0.2	0	0	0.7	0	0.1	0.5	0.2	0.2
M548E1	0	0.1	0	0	0.2	0	0.2	0.4	0.2	0.1
M151A2	0	0.1	0	0	0.2	0	0.2	0.3	0.4	0.1
M715E1	0	0.1	0	0	0.2	0	0.1	0.3	0.3	0.1
M35A2	0	0	0	0	0.2	0	0.1	0.3	0.3	0.1
M49A2C	0	0	0	0	0.2	0	0.1	0.3	0.3	0.1
M813	0	0.1	0	0	0	0	0.1	0.3	0.3	0.1
M821	0	0	0	0	0	0	0.1	0.3	0.3	0.1
M816	0	0.2	0	0	0.7	0	0.1	0.5	0.3	0.2
M125E1	0	0.2	0	0	0.7	0	0.1	0.5	0.3	0.2
M818-M127A1C	0	0.4	12.6	0	1.0	16.5	0.1†	0.7†	13.8†	5.0†
TDW901	0	0.4	0	0	0	0	0.1	0.2	0.1	0.1
M60A2	0	0.1	0	0	0.2	0	0.1	0.3	0.1	0.1

* 51 jobs, average one-way distance 13.1 miles.
** 51 jobs, average one-way distance 13.8 miles.
† Values suspect because some NOGO s probably were not called (Appendix A, paragraphs 14-17).

Table D41

Percentages of Tactical Delay Jobs Involving Some NOGO Situations
West Germany

Vehicle	Primary* Dry	Primary* Wet	Primary* Snow	Secondary** Dry	Secondary** Wet	Secondary** Snow	Tertiary* Dry	Tertiary* Wet	Tertiary* Snow	All Routes & Conditions
M561	0	0	0	0	0.1	0.1	0.2	0.2	0.2	0.1
M656	0	0	0	0	0.1	0.1	0.2	0.2	0.2	0.1
M520E1	0	1.7	0	0	2.0	0.1	0.1	2.0	0.1	0.7
M559	0	1.7	0	0	2.0	0.1	0.1	2.0	0.1	0.7
M553	0	1.7	0	0	2.0	0.1	0.1	2.0	0.1	0.7
M548E1	0	0.1	0	0	0.4	0.1	0.2	0.4	0.2	0.2
M151A2	0	0	0	0	0.1	0.2	0.5	0.4	0.4	0.2
M715E1	0	0.1	0	0	0.2	0.2	0.2	0.3	0.2	0.1
M35A2	0	0	0	0	0.1	0.2	0.2	0.2	0.1	0.1
M49A2C	0	0	0	0	0.1	0.2	0.2	0.2	0.2	0.1
M813	0	0.1	0	0	0.4	0.2	0.1	0.3	0.2	0.1
M821	0	0	0	0	0.1	0.2	0.2	0.2	0.2	0.1
M816	0	1.7	0	0	2.0	0.2	0.2	2.1	0.2	0.7
M125E1	0	1.7	0	0	2.0	0.1	0.1	2.1	0.2	0.7
M818-M127A1C	0	1.8	13.9	0	2.4	16.9	0.2†	2.4†	14.9†	5.8†
TDW901	0	0	0	0	0.1	0	0.1	0	0	0†
M60A2	0	0.1	0	0	0.4	0	0.1	0.4	0.1	0.1

* 40 jobs, average one-way distance 13.8 miles.

** 40 jobs, average one-way distance 15.1 miles.

† Values suspect because some NOGO's probably were not called (Appendix A, paragraphs 14-17).

secondary job routes involved no linear-feature-crossing times, but on the tertiary route, linear-feature-crossing times account for 5-10 percent of total job travel times.

65. Tables D42 and D43 show the percentage of jobs in the two study areas that involved total linear-feature-crossing times of more than 30 min, the level selected to indicate serious linear-feature-crossing problems along a job route. In the Mid-East study area, such delays occurred only on the secondary routes under wet conditions and affected only selected vehicles. The difficulties are associated with fording capabilities and traction on hard, slippery banks. In the West Germany study area, crossing problems were evident only on the tertiary routes and affected all vehicles in 4-12 percent of all jobs.

Job route and off-road performance

66. The evidence of the job speeds, NOGO levels, and linear-feature-crossing times, when compared with corresponding figures based solely on the link travel performance, clearly indicates that the job routes developed in the scenario play involved relatively little off-road travel, even when the partial interdiction of the MSR (tertiary route) was played. As a result, the off-road mobility performance of the vehicles was not taxed.

Vehicle Performance As A Function Of Percentage of Travel Off-Road

67. To examine the relative performance of the study vehicles under the full range of possible mission requirements for off-road travel, from all on road to all off road, the link performance data were used to develop speed profiles showing overall area-wide average vehicle speed as a function of percentage of travel off road. Figures D21-D26 show these percent-off-road speed profiles for the three conditions in each of the two study areas. Profiles for the 17 study vehicles are grouped in various ways for different area-condition situations. To place all profiles for each situation on a single plot for direct comparison, bands are shown in the figures where this grouping occurs. Those vehicle percent-off-road speed profiles that define the upper and

Table D42

Percentages of Jobs Involving Linear Feature Crossing Times of More Than 30 Min

Mid-East

Vehicle	Secondary Route, Wet Condition Only* Tactical Delay	Tactical Attack	Logistic	All
M561	8.3	0	0	2.8
M656	0	0	0	0
M520E1	0	0	0	0
M559	0	0	0	0
M553	0	0	0	0
M548E1	8.3	0	0	1.0
M151A2	29.2	23.1	4.9	19.1
M715E1	8.3	2.6	0	3.6
M35A2	8.3	0	0	2.8
M49A2C	8.3	0	0	2.8
M813	0	0	0	0
M821	0	0	0	0
M816	0	0	0	0
M125E1	0	0	0	0
M818-M127A1C†	0	0	0	0
TDW901	29.2	15.4	2.7	15.7
M60A2	4.2	0	0	1.4

NOTE: Secondary Route Statistics:
Logistic - 182 jobs, average one-way distance 8.1 miles.
Tactical attack - 39 jobs, average one-way distance 6.8 miles.
Tactical delay - 24 jobs, average one-way distance 10.3 miles.

* No vehicles had linear-feature-crossing times of more than 30 min on primary and tertiary routes or during dry and sand conditions for secondary routes.

† All values suspect because some NOGO probably were not called (Appendix A, paragraphs 14-17).

Table D43

Percentages of Jobs Involving Linear Feature-Crossing Times of More Than 30 Min West Germany

Vehicle	Tertiary Route Only*, All Conditions: Tactical Delay	Tactical Attack	Logistic	All
M561	2.5	9.1	6.3	6.0
M656	2.5	9.1	6.0	5.9
M520E1	2.5	9.1	6.3	6.0
M559	2.5	9.1	6.0	5.9
M553	2.5	9.1	6.0	5.9
M548E1	2.5	7.8	2.3	4.2
M151A2	8.3	15.7	10.9	11.6
M715E1	4.2	11.7	7.0	7.6
M35A2	4.2	10.5	6.1	6.9
M49A2C	4.2	10.5	4.9	6.5
M813	4.2	10.5	6.6	7.1
M821	2.5	9.1	4.9	5.5
M816	4.2	10.5	6.4	7.0
M125E1	8.3	15.7	6.7	10.2
M818-M127A1C†	8.3	15.7	10.0	11.3
TDW901	8.3	15.7	9.9	11.3
M60A2	4.2	11.7	4.0	6.6

NOTE: Tertiary Route Statistics:
Logistic - 343 jobs, average one-way distance 18.6 miles.
Tactical Attack - 51 jobs, average one-way distance 13.1 miles.
Tactical Delay - 40 jobs, average one-way distance 13.8 miles.

* No vehicles had linear-feature crossing times of more than 30 min. on primary and secondary routes.

† All values suspect, because some NOGO probably were not called (Appendix D, paragraphs 14-17).

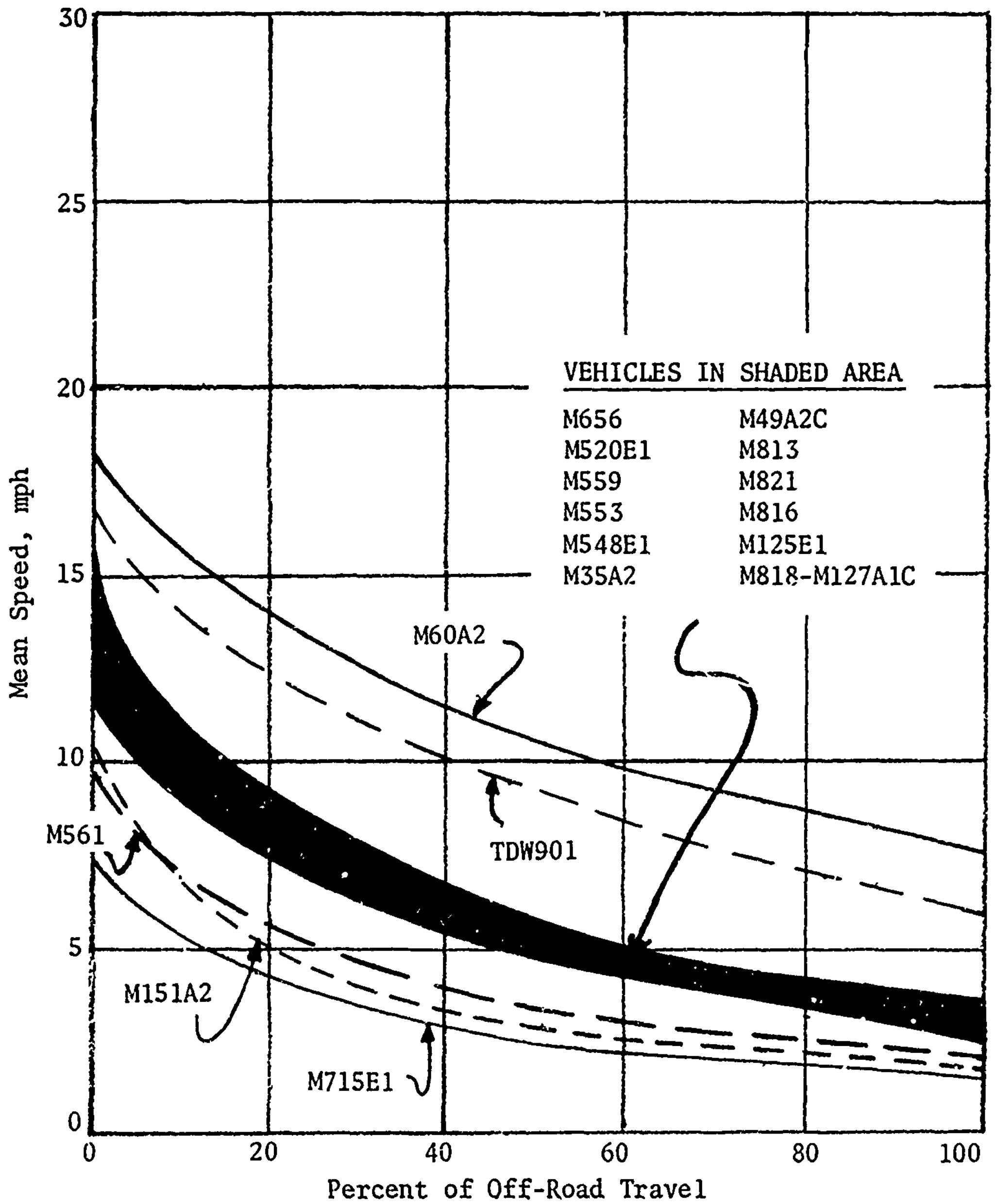


Figure D21. Mean speed versus percent off-road travel, Mid-East, dry condition

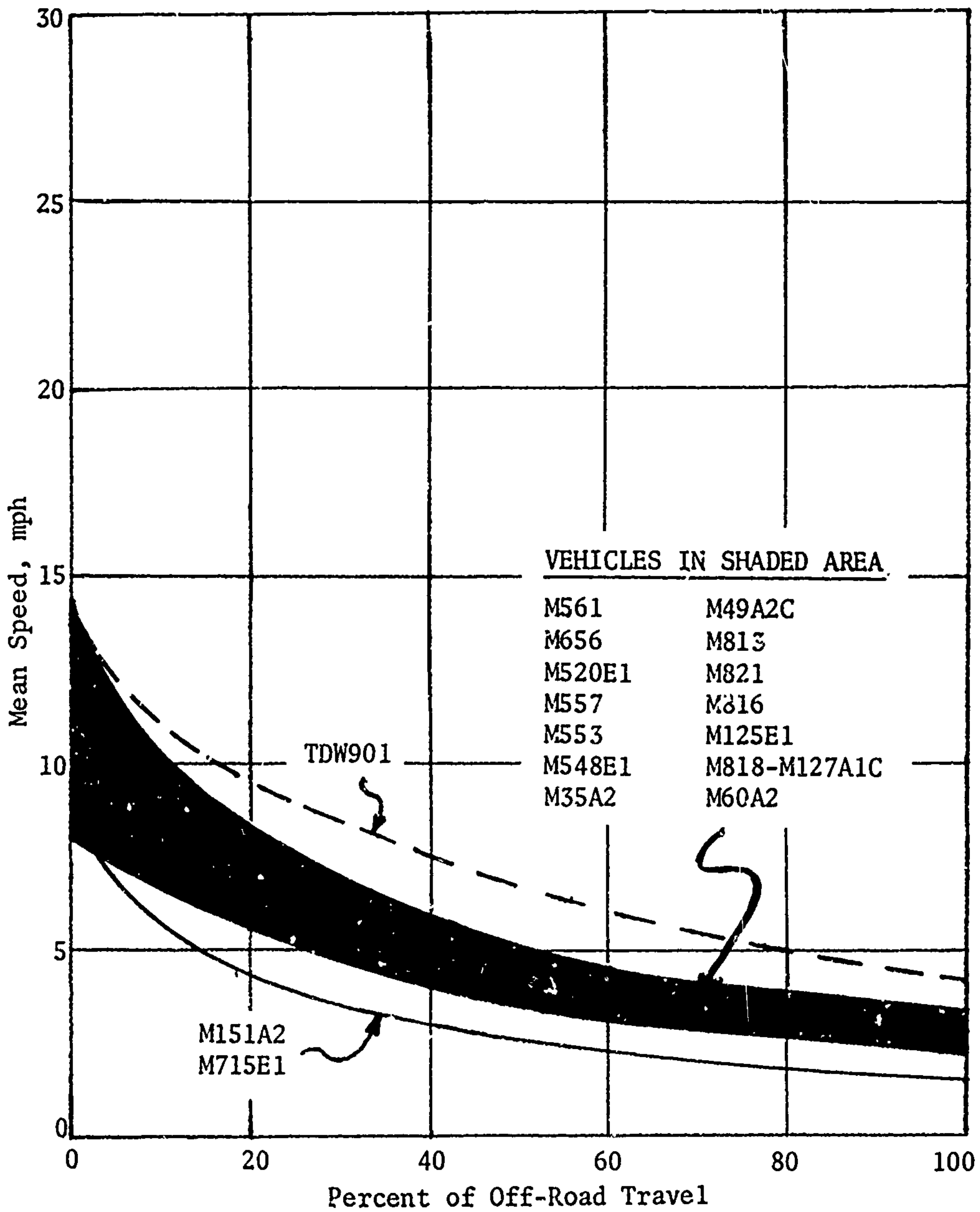


Figure D22. Mean speed versus percent of off-road travel, Mid-East, wet condition

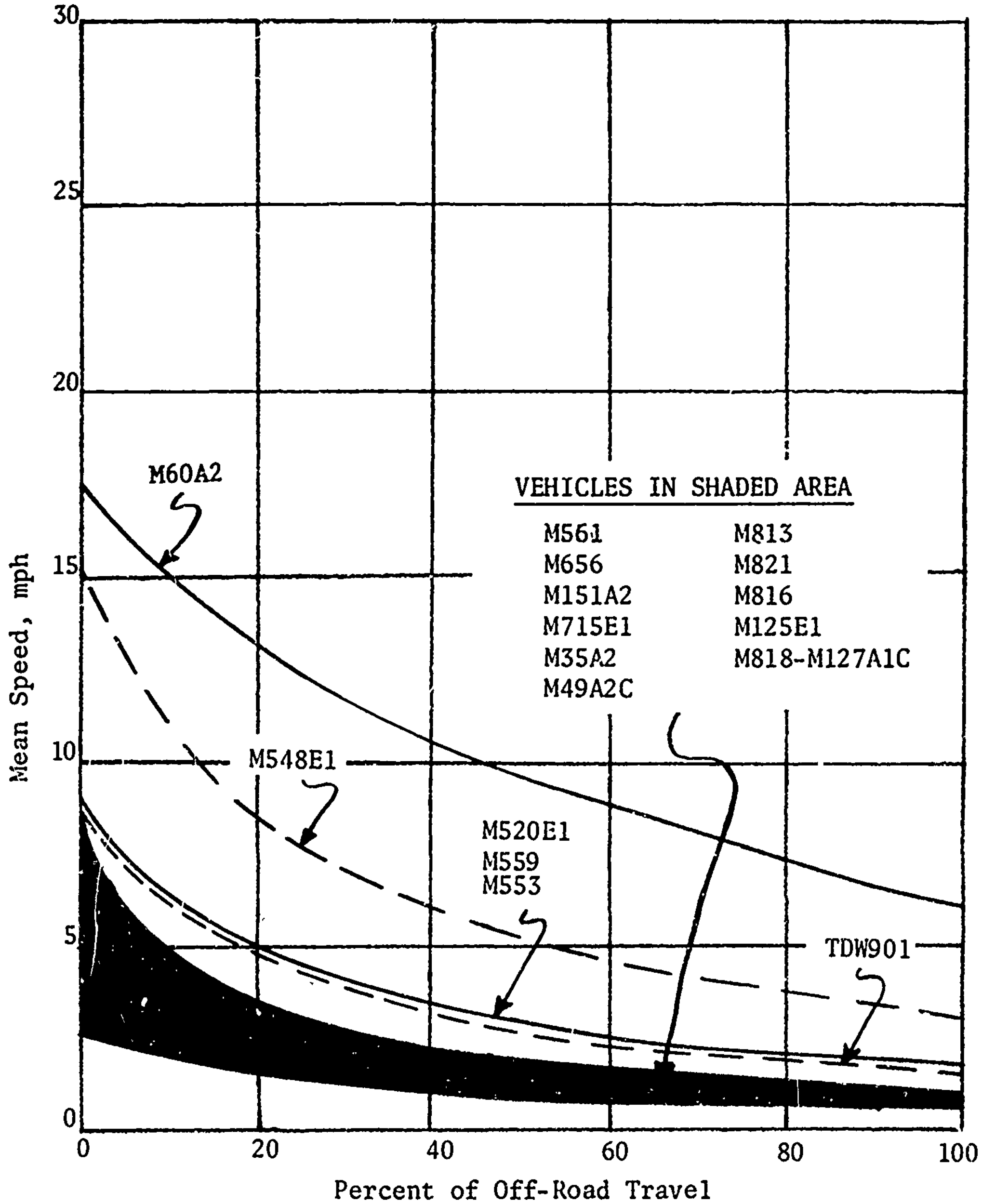


Figure D23. Mean speed versus percent of off-road travel, Mid-East, sand condition

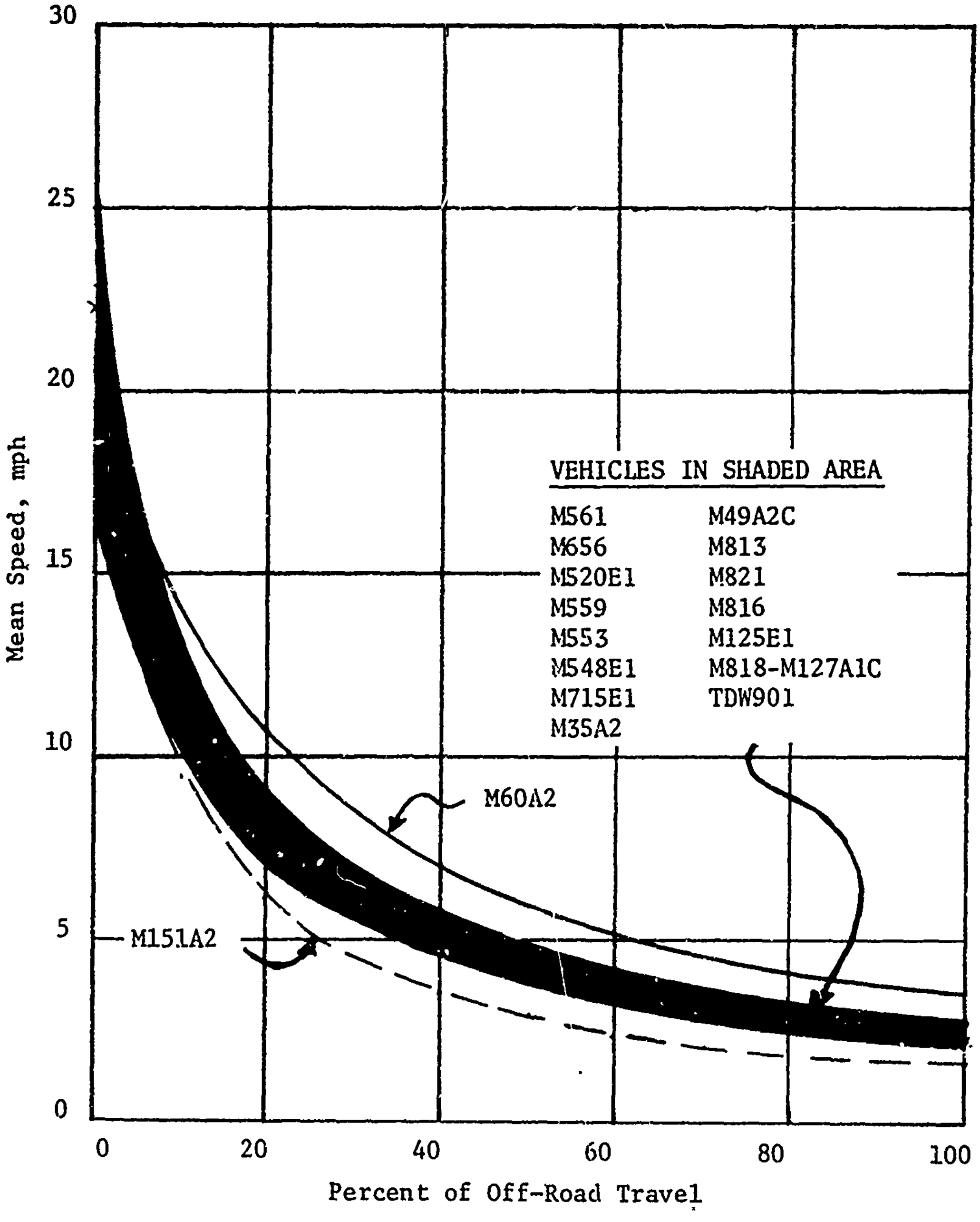


Figure D24. Mean speed versus percent of off-road travel, West Germany, dry condition

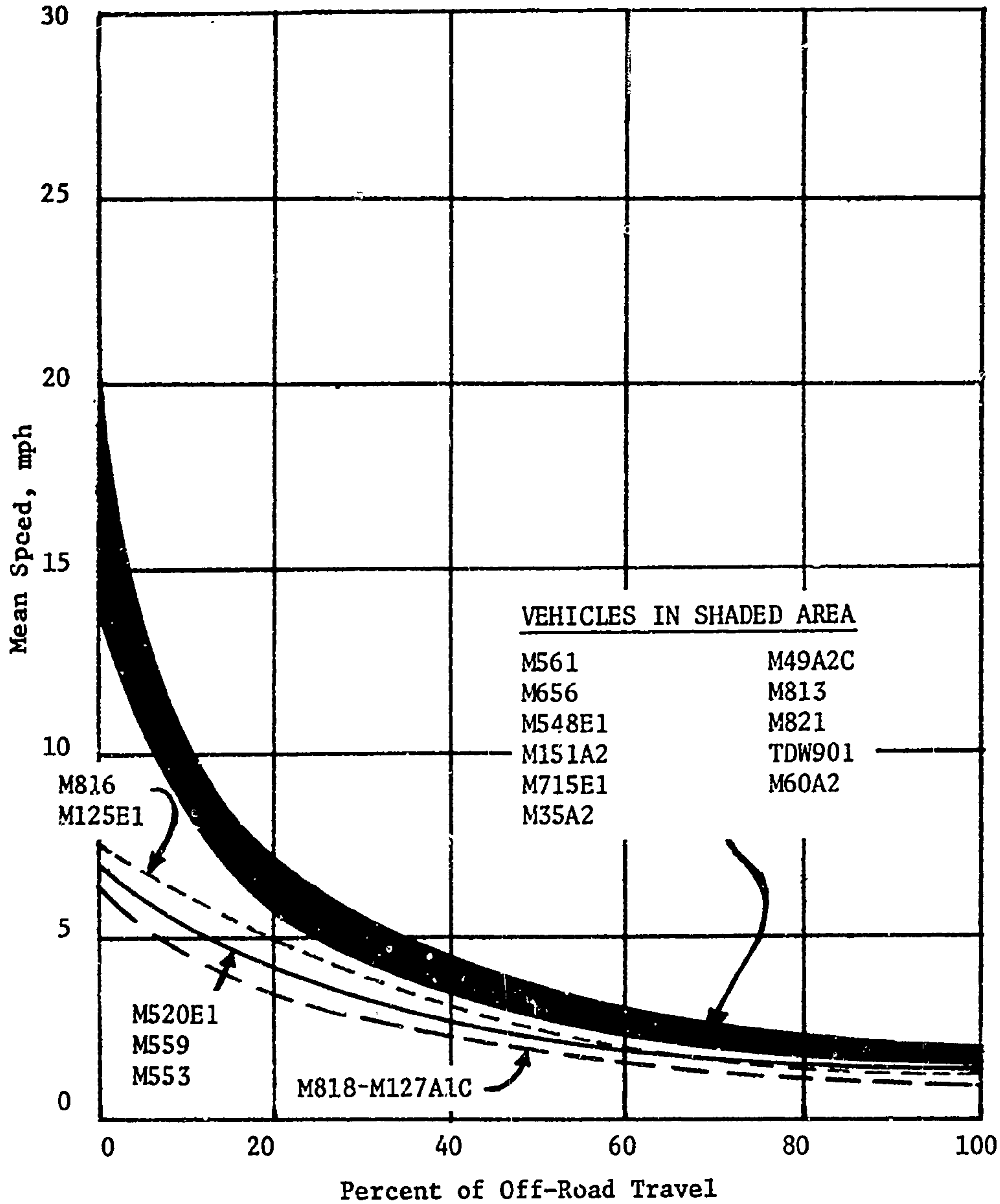


Figure D25. Mean speed versus percent of off-road travel, West Germany, wet condition

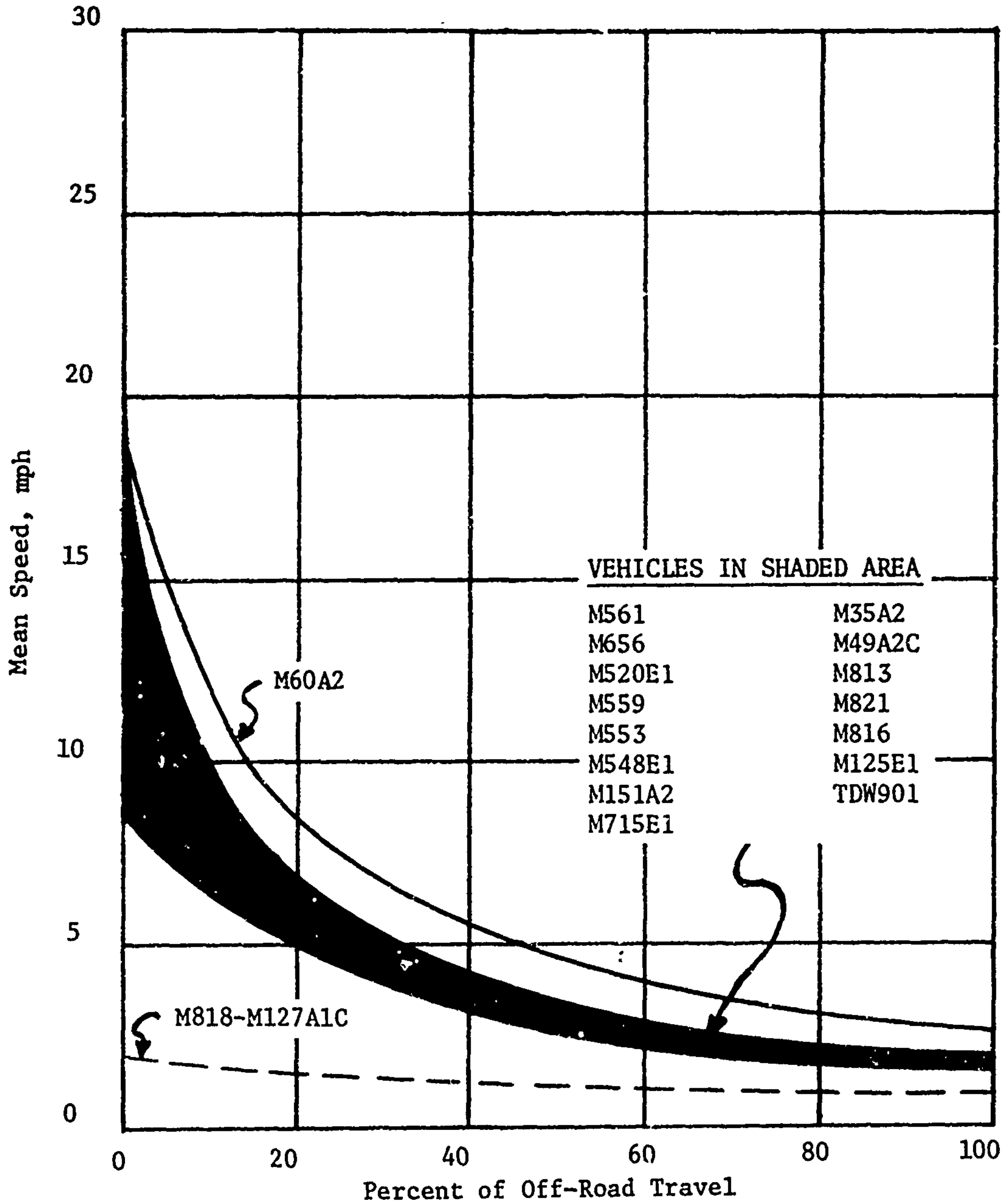


Figure D26. Mean speed versus percent of off-road travel, West Germany, snow condition

lower bounds of the band are indicated. Profiles for vehicles not specifically identified in a plot lie within the band.

68. Note that the speeds at zero percent off road are the average speeds on all roads and trails within the study area route network, under the conditions specified, and may include some linear feature crossings and NOGO's. Thus, the all on-road speeds (zero off-road) cannot be interpreted as maximum vehicle speeds on the best roads or always under the best conditions. Similarly, speeds for 100 percent off road are area-wide averages, including all areal terrain and all NOGO and linear-feature-crossing-time assessments. Between zero and 100 percent, off-road travel is on the basis of no route selection to avoid the worst areas (as is basic to the areal off-road and on-road speed profiles presented in paragraphs 26-39).

69. Once more, the speed levels are not exciting by sports car standards, and, again, this obscures some potentially important absolute and relative differences. With this in mind, the figures require little comment.

70. In the Mid-East study area under wet and dry conditions, the TDW901 shows outstanding performance, amd the smaller vehicles (M151A2, M561, and M715E1) and the M818-M127A1C tractor-trailer show least performance. The GOER vehicles, characterized by the M520E1, are at the upper bound of the bands. In the Mid-East study area as an all-sand-dune terrain, the tracked M548E1 is outstanding, and among the wheeled vehicles, the speed performances of the M520E1 GOER and the TDW901 are 50-100 percent greater than the best of the remaining vehicles from about 10 percent off road on up to 100 percent.

71. In the West Germany study area, discrimination is less under all three conditions. The M60A2 defines the total upper bound in all cases.

72. The statistical sampling program by means of which the percent-off-road speed profiles are generated from the link speed data also develops the standard deviations of the samples. In the middle range of percents off road, the standard deviation for speeds in the Mid East study area is of the order of 3 percent of the speed; in the West

Germany study area, 2 percent. Thus 95 percent of all values for a given vehicle and condition can be expected to lie within ±6 percent of the curve in the Mid-East area and ±4 percent in the West Germany area.

Vehicle Performance in Combat Unit Areas

73. Over the course of the several scenario days that were detailed in the map play, combat units were designated as occupying at one time or another a total of 67 sq miles of the areal terrain in the Mid-East study area (6 percent of the total area mapped in terms of mobility parameters) and 166 sq miles in the West Germany area (14 percent). Individual combat unit areas were of the order of 0.5-0.7 sq miles each. The maximum travel required within a single area from the supply delivery point selected during the map play to the farthest point on the edge of the area was usually one ell under one mile.

74. Table D44 shows the performance of the study vehicles in the areal terrain within these unit areas during the wet condition in the Mid-East and West Germany study areas. Both the average speed in the 90 percent best of the terrain (V_{90}) and the percentages of the combined unit areas that were NOGO are shown. Because of the short travel distances involved (perhaps 0.4 miles average), the latter figure is the more appropriate basis upon which to judge vehicle capability for delivering fuel and ammunition to combat vehicles and batteries in place, without movement of the combat vehicles or intermediate handling.

75. Percentages of the areal terrain within the combat unit areas that were NOGO are very nearly the same as for the two study areas as a whole as determined by the network traverses when treated as being off road (Tables D6 and D7, off road, wet).[1] This indicates that the area-wide values for off-road performance measures in areal terrain, discussed in the earlier paragraphs, are suitable indicators of relative vehicle performance within the combat unit areas.

76. Difficulties with areally occurring obstacles within the combat unit area were the principal reasons for NOGO of all vehicles in the Mid-East study area, with some slippery traction problems also

Table D44

Vehicle Performance in Areal Terrain

Occupied by Combat Units

Wet Condition Only

	Mid-East		West Germany	
Vehicle	NOGO percent	V_{90} mph	NOGO percent	V_{90} mph
M561	10.0	5.3	6.0	12.2
M656	8.5	9.8	4.8	12.0
M520E1	1.6	4.8	16.2	1.2
M559	1.6	4.7	14.6	1.4
M553	1.6	4.8	14.6	1.5
M548E1	8.7	8.1	11.4	4.0
M151A2	18.1	1.0	9.8	12.5
M715E1	22.0	0.7	8.0	10.6
M35A2	9.0	9.2	5.4	12.1
M49A2C	9.1	9.2	5.4	12.0
M813	7.9	6.5	6.4	9.4
M821	6.2	7.1	4.9	8.6
M816	8.3	6.1	17.0	1.1
M121E1	3.8	7.3	13.7	1.9
M818-M127A1C	7.8	6.3	20.2	0.8
TDW901	2.6	11.9	3.2	11.5
M60A2	6.3	7.9	6.5	10.5

causing problems for all vehicles. The same situation was found in the West Germany study area, except that, for the GOER vehicles (M520E1, M559, and M553), the 10-ton M125E1, and the M818-M127A1C semitrailer rig, the order of importance was reversed because of some additional weak soil problems.

APPENDIX E: COMPUTATION OF A MISSION-ORIENTED AVERAGE SPEED BASED ON A STATISTICAL MISSION DEFINITION AND VEHICLE PERFORMANCE STATISTICS FOR AN AREA AND CONDITION

1. Statistical measures of several aspects of a vehicle's performance in a given terrain and weather condition may be computed from the extensive data developed in the course of making job time predictions. Principal among these are:

   a. The off-road speed profile, which depicts a vehicle's average speed in areal off-road terrain as a function of the percentage of the area under study that it is able to avoid, under the assumption that it avoids those areas posing the greatest mobility difficulty

   b. The on-road speed profile, which depicts average vehicle speed on the road and trail network of the study area in the same manner.

   c. The percentage of off-road travel time that is spent in negotiating linear features during cross-country operations in the area.

   d. The overall average speed off-road including linear feature crossing and NOGO time assessments.

   e. The composition of the area road and trail network in percentages of total network distances that are on superhighways, primary and secondary roads, and tertiary roads and trails.

2. If a level of mission performance can be stated in terms of (a) the expected percentage of operating distance in the area that will be off-road, (b) the relative severity of off-road areal terrain that should be encompassed, and (c) the types of on-road situations to be encountered, the statistics mentioned in paragraph 1 can be used to develop an area-wide average speed associated with the mission statement. Values drawn from the component statistical analyses are as follows:

V_c = the speed from the off-road speed profile (mph) corresponding to C.

C = the percentage of the off-road terrain that should be negotiable.

L = the percentage of total travel time over the route network, considered as an all off-road traverse, that is spent negotiating is spent negotiating linear features. (This figure is available in the link statistics for each vehicle, area, and condition.)

V_R = the speed from the on-road speed profile (mph) corresponding to R.

R = the percentage of the road and trail network that should be negotiable.

V_O = overall average off-road speed.

3. Given these factors and P , the percentage of expected off-road operating distance, an area-wide average speed, V_W , is given by

$$V_W = \frac{100}{P\left(\frac{1}{V_C} + \frac{L}{100\ V_O}\right) + \frac{100 - P}{V_R}} \text{, mph} \qquad \text{(E1)}$$

To reflect the same notion of route selection to avoid the worst situations, which is intrinsic to the on- and off-road speed profiles, V_C may be used in place of V_O, resulting in

$$V_W = \frac{100}{\frac{P}{V_C}\left(1 + \frac{L}{100}\right) + \frac{100 - P}{V_R}} \text{, mph} \qquad \text{(E2)}$$

Equations E1 and E2 are bounds on the possible influence on the rating speed assumptions concerning linear-feature-crossing times. The lower bound value, Equation E2, is used in developing rating speeds discussed in the main text (paragraphs 85-95).

4. In general, the extent of the road and trail network to be utilized will be related to the extent to which trails in the area are expected to be negotiated by the vehicle. If this is considered in terms of a percent, T , where that percent is made up of those trails presenting the least mobility difficulty, then

$$R = 100 - N(1 - T/100) \qquad \text{(E3)}$$

where N = the percentage of the total road and trail network that is in trails.

5. Equation E3, applied to the road and trail networks in the Mid-East and West Germany study areas using the compositions shown in Table 2 of the main text, leads to values for R of 51 percent and 87 percent, respectively, when T = 10 percent; 73 percent and 93 percent, respectively,

when T = 50 percent.* (These values are used to establish V_R --from the appropriate off-road speed profiles--used in turn to calculate V_W in accordance with the preliminary quantifications for on-road and tactical support mobility levels proposed in Table 12 of the main text.)

6. There is one anomaly in the available statistical data (paragraph 1) as applied to this calculation. The off-road and on-road speed profiles are derived by assigning a speed of 0.1 mph for NOGO distances, whereas in computing the percentage of time spent crossing linear features, developed as a part of the link statistics, NOGO's are not permitted to increase in-link travel time by more than 60 min. Thus, the V_W values assigned give more weight to areal and road terrain NOGO situations than to linear-feature-crossing NOGO's. The bias introduced is considered to be minor, however.

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* Note that the percentage of the road and trail network that is in trails must be computed <u>without</u> the off-road traverses, which form part of the complete route network.

APPENDIX F: DATA USED TO CHARACTERIZE STUDY VEHICLES FOR PREDICTIONS WITH AMM

1. Extensive data are required to characterize a vehicle in order to predict performance with AMM. These complete data, for each of the 17 study vehicles, are given in Tables F1-F6. All vehicles are described carrying their rated payloads and with tires at recommended cross-country inflations and corresponding deflections. Reduced inflation pressures allowable for operation in sand terrains are also specified.

2. Power-train characterizations used were extracted from Aberdeen Proving Ground engineering test data for all vehicles except the TDW901 and the M49A2C. For the later vehicles, power-train performance was computed from engine and power-train data in a submodel that is integral to AMM.

3. Both field experience and simulations have shown that vehicle dynamic responses, while a vehicle is traversing rough terrain and crossing minor obstacles, have a strong influence on actual vehicle speed performance. AMM is so structured that values used in it for these critical vehicle characteristics may be those determined by means of dynamic simulations or from experimental data. To ensure that the dynamic response characterization of all study vehicles, in the terms required by AMM, was as realistic and consistent as possible, this characterization was in all cases (except for the M125E1, 10-ton, 6x6) based on measurements made in special dynamics tests of prototype vehicles in carefully described conditions. Many of these tests were conducted by Project MASSTER at Fort Hood, Texas, under a special project.[6] The required dynamics response data for the M125E1, 10-ton, 6x6, were developed by means of the two-dimensional vehicle dynamics simulation that is available as a module of AMM.[7,8]

4. Vehicle traffic on unimproved roads and trails smooths small irregularities and worsens those large ones that are near vehicle resonances at prevailing traffic speeds. As a result, the roughness of a road or trail, quantified in terms of root mean square (rms) elevation of its properly detrended profile, tends to be composed of high-frequency

Table F1

Values of Vehicle Characteristics Used in AMC-71 Ground Mobility Model

	Vehicle Characteristics		Vehicles															
			High-Mobility Vehicles							Standard Mobility Vehicles								
No.	Identification	Dimensions	M561	M656	M548E1	M520E1	TDW901	M553	M559	M151A2	M715E1	M35A2	M49A2C	M816	M821	M813	M123E1	M187 M127A1C	M60A2
1	Vehicle type (SVTH = 0 for tracked and 1 for wheeled)	—	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Gross vehicle weight	kips	9.2	25.8	26.5	43.2	39	46.5	46.4	3.2	8.4	19.3	20	43.5	39.3	32.5	51.6	589	104
3	Track type (SFL = 0 for flexible and 1 for girderized)	in.	NA*	NA	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
4	Grouser height for tracks; number of tires for wheeled	—	6	8	1.0	4	8	4	4	4	4	10	10	10	10	10	10	18	1
5	Tire ply rating	—	4	10	NA	10	12	10	10	6	8	8	8	12	20	12	20	12	NA
6	Gross rated horsepower	bhp	103	210	202	213	225	213	213	71	116	140	140	250	250	250	300	250	750
7	Number of tracks or tires	—	6	8	2	4	8	4	4	4	4	10	10	10	10	10	10	18	2
8	Number of axles	-	3	4	NA	2	4	2	2	2	2	3	3	3	3	3	3	5	NA
9	Vehicle width	in.	84	96	105.75	108	96	108	112	64	85	96	93	97.5	115	100.75	116	97	143
10	Vehicle length	in.	229.8	276	226.5	375	294	408	394.6	132.7	209.75	278.28	277	345	389.5	316.75	320	525	273
11	Track width or nominal tire width	in.	11	16	15	18	16	18	18	7	9	9	14	11	14	11	14	11	28
12	Wheel rim diameter	in.	18	20	NA	33	20	33	33	16	16	20	20	20	20	20	24	20	NA
13	Recommended tire pressure (cross-country)	psi	12	30	NA	27.5	13.5	27.5	27.5	20	27.5	35	35	35	35	35	40	35	NA
14	Recommended tire pressure (sand)	psi	12	15	NA	15	7	15	15	15	15	15	15	15	20	15	20	15	NA
15	Area of one-track shoe (tracked) or number of wheels (wheeled)	in.	6	8	90	4	8	4	4	4	4	10	10	10	10	10	10	18	194
16	Number of bogies (tracked) or chain indicator wheeled (0 = chains, 1 = chains)	—	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	Vehicle ground clearance at the center of greatest wheel span	in.	15.8	20	NA	29	34	29.3	29.3	12.7	15.5	19.1	19	22.5	22.5	22.5	26	23	NA
18	Minimum vehicle ground clearance	in.	14.6	12	16	24	15	24	24	9	10	12.87	12.9	11.6	16	11.5	15.88	11.5	18
19	Rear end clearance (vertical clearance of vehicle's trailing edge)	in.	15.8	52	23	31	32	31	31	18	26.5	32	33.5	29	28	34.6	28	32	40
20	Vehicle departure angle	deg	52	61.5	35	35	65	35	35	37	25	40	40	38	24	39	45	70	42.5
21	Vertical clearance of vehicle's leading edge	in.	27	32	50	48	45	31	48	18	19	35	36.5	32	37	32	40	32	60
22	Vehicle approach angle	deg	62.5	50	57	35	55	35	35	66	45	40	40	35	37.5	35	30	35	90
23	Length of track on ground or wheel diameter	in.	40	44	120	69	52	69	69	30	32	38	38	42	48	42	52	42	171
24	Height of vehicle pushbar	in.	27	36	50	48	45	48	48	18	19	35	36.5	32	37	32	40	32	45
25	Distance between first and last wheel center lines	in.	165.5	206	NA	235	160	235	235	85	126	178	178	206	243	206	199.5	429	NA
26	Horizontal distance from the center of gravity to the front wheel center lines	in.	90.12	110	93.5	111	108	109	116.6	46.8	81	88	93.2	151.2	148.4	119.7	123.77	108	109
27	Vertical distance from the center of gravity to the road wheel center lines	in.	16.5	15.3	15	13.1	32	17.3	17.3	11.6	15.82	22.3	34.0	27.12	29.2	30.58	50	13.9	36
28	Maximum span between adjacent wheel center lines	in.	84.8	90	NA	235	102	235	235	85	126	130	130	152	187	152	133.45	183	NA
29	Angle between a line parallel to the ground surface and the line connecting the center of gravity and the center of the rear wheel (road wheel or idler). The wheel is the one used to determine departure angle.	deg	NA	NA	13.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.5
30	Distance from the center of gravity to the center of the rear wheel (road wheel or idler). The wheel is the one used to determine departure angle.	in.	NA	NA	74	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	142
31	Vertical distance from the ground to the center of the rear wheel (road wheel or idler)	in.	NA	NA	18	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	36
32	Track thickness plus the radius of the rear wheel (road wheel or idler). The wheel is the one used to determine departure angle. (wheeled = NA)	in.	18.6	20.44	14	31.7	22.5	31.7	31.7	13.44	15.18	17.7	17.7	18.28	22.37	18.72	22.64	18.58	18
33	Loaded rolling radius of tire (cross-country tire pressure) or sprocket pitch radius	in.	18.6	20.44	NA	31.7	22.5	31.7	31.7	13.44	15.18	17.7	17.7	18.26	22.37	18.72	22.64	18.58	NA
34	Height of rigid point used to determine approach angle	in.	24.13	32	23	48	32	48	48	18	19	35	36.5	32	37	32	40	32	45
35	Maximum braking force the vehicle develops	--	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
36	Loaded wheel radius (at sand-tire pressure)	in.	18.16	19.66	NA	29.9	21.7	29.9	29.9	13.16	14.61	17.36	17.32	17.01	21.83	17.68	21.67	17.46	NA
37	Total ground-contact area	$in.^2$	NA	NA	3600	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	9576
38	Distance vehicle spans before significant motion begins	in.	20	22	60	34.5	26	34.5	34.5	15	16	19	19	21	24	21	26	21	67
39	Maximum force the pushbar can withstand	kips	9.2	25.8	53	43.2	39	46.5	46.5	3.2	8.4	19.3	20	32	39.3	32.5	51.6	58.9	208
40	Maximum axle load/gross vehicle weight	—	0.36	.25	NA	.53	0.29	.54	.54	.56	.64	.36	.35	.42	.35	.35	.38	.36	NA
41	Vehicle rated horsepower per ton	hp/ton	22.5	16.3	15.3	9.9	11.5	9.2	9.2	44.4	27.6	14.5	16	11.5	12.7	16.3	11.6	8.5	15
42	Transmission type (0 = automatic, 1 = manual)	—	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0
43	Final drive gear ratio	—	5.57	6.40	4.31	14.69	6.4	14.69	14.69	4.27	5.87	6.27	6.27	6.44	6.44	6.44	9.02	6.44	5.08
44	Final drive gear efficiency	—	.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
45	Number of gears in transmission	—	8	6	2	6	10	6	10	4	8	10	10	10	10	10	6	10	12
46	Gear ratios for transmission	—								See Table 2									
47	Transmission efficiency	—	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
48	Number of point pairs in array TTE	—	30	24	26	28	13	28	28	19	29	34	34	33	33	33	40	33	17
49	Array containing vehicle speed versus tractive force curve	—								See Table 3									
50	Number of point pairs in array VOOB	—	11	15	12	11	15	11	11	13	14	14	16	14	20	14	20	14	10
51	Array containing vehicle velocity versus obstacle height at 2.5-g vertical acceleration	—								See Table 4									
52	Number of points in array VRIDE (cross-country)	—	16	19	13	10	18	13	13	16	20	16	16	13	10	13	13	14	12
53	Array containing ride dynamics versus speed curve (cross-country)	—								See Table 5									
54	Number of points in array VRIDE (roads and trails)	—	15	25	13	10	21	10	11	16	20	16	16	10	10	10	18	13	12
55	Array containing ride dynamics versus speed curve (roads and trails)	—								See Table 6									

* NA means not applicable.

Table F2

Transmission Gear Ratios Used for Self-Propelled Vehicles
Vehicle Characteristic No. 46 in Table 1

Vehicle	Gear Ratios for Transmission									
M561	12.64	7.06	6.41	3.58	3.06	1.79	1.71	1.00		
M656	5.49	3.95	2.79	2.01	1.44	1.04				
M548E1	17.12	13.31								
M520E1	5.22	3.01	2.30	1.73	1.33	1.00				
TDW901	11.18	8.04	4.98	3.58	2.91	2.09	1.93	1.39	1.39	1.00
M553	5.22	3.01	2.30	1.73	1.33	1.00				
M559	5.22	3.01	2.30	1.73	1.33	1.00				
M151A2	5.71	3.18	1.67	1.00						
M715E1	12.54	6.40	6.06	3.31	3.09	1.96	1.69	1.00		
M35A2	9.94	5.50	5.02	3.21	2.78	1.98	1.62	1.56	1.00	0.79
M49A2C	9.94	5.50	5.02	3.21	2.78	1.98	1.62	1.56	1.00	0.79
M816	12.29	6.88	6.07	3.62	3.40	2.02	1.79	1.58	1.00	0.78
M821	12.29	6.88	6.07	3.62	3.40	2.02	1.79	1.58	1.00	0.78
M813	12.29	6.88	6.07	3.62	3.40	2.02	1.79	1.58	1.00	0.78
M125E1	4.00	2.28	2.00	1.41	1.00	0.71				
M818-M127A1C Trailer	12.29	6.88	6.07	3.62	3.40	2.02	1.79	1.58	1.00	0.78
M60A2	3.50	1.26								

Table F3

Tractive Force-Speed Relations for Vehicle Characteristics No. 40 in Table 3

High-Mobility Vehicles

M561		M656		M548E1		M520E1		Lunabile		M553		M559	
Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb
0	8320	0	21,600	0	19,750	0	36,500	0	25,000	0	38,500	0	36,500
3.4	8310	1.0	20,440	0.8	19,650	0.4	36,500	1.5	21,000	0.4	36,500	0.4	36,500
4.0	8110	2.6	16,440	1.5	17,050	0.9	32,500	2.5	17,300	0.9	32,500	0.9	32,500
4.4	7640	4.0	11,540	2.6	13,030	1.2	28,500	4.5	12,000	1.2	28,500	1.2	28,500
4.5	6940	6.2	9,710	3.3	11,050	1.6	24,500	5.0	10,400	1.6	24,500	1.6	24,500
4.6	4770	6.3	8,010	4.2	9,050	2.1	20,500	7.5	7,000	2.1	20,500	2.1	20,500
5.2	4740	7.2	7,920	5.5	6,500	2.9	16,500	10.0	5,000	2.9	16,500	2.9	16,500
6.3	4455	7.6	7,620	6.4	6,565	3.9	12,500	12.5	4,000	3.9	12,500	3.9	12,500
7.0	4315	8.7	6,020	7.2	6,470	4.7	9,700	15.0	3,500	4.7	9,700	4.7	9,700
7.5	4030	10.0	5,040	8.0	6,000	5.6	8,310	20.0	2,250	5.6	8,310	5.6	8,310
7.8	3663	12.2	5,050	9.6	5,190	7.4	6,830	30.0	2,200	7.4	6,830	7.4	6,830
8.3	3085	12.3	4,150	10.0	4,300	8.4	5,940	35.0	1,000	8.4	5,940	8.4	5,940
8.4	2501	13.8	4,050	10.1	3,800	10.0	5,750	35.0	—	10.0	5,750	10.0	5,750
11.7	2491	16.7	3,660	11.3	3,775	11.1	5,550			11.1	5,550	11.1	5,550
12.0	2470	16.1	3,260	14.0	3,740	12.1	5,040			12.1	5,040	12.1	5,040
14.2	2315	20.0	3,140	16.0	3,650	12.6	4,370			12.6	4,370	12.6	4,370
15.0	2130	22.9	2,990	18.0	3,270	14.0	4,200			14.0	4,200	14.0	4,200
16.0	2035	24.0	2,600	19.3	3,030	15.0	4,100			15.0	4,100	15.0	4,100
16.9	1938	27.9	2,220	21.8	2,605	16.0	3,810			16.0	3,810	16.0	3,810
17.0	1730	33.0	1,850	24.0	2,310	16.9	3,220			16.9	3,220	16.9	3,220
17.9	1270	33.1	1,700	26.0	2,160	18.6	3,140			18.6	3,140	18.6	3,146
24.6	1265	38.7	1,650	28.0	2,110	20.0	2,850			20.0	2,850	20.0	2,850
27.5	1170	50.0	1,300	32.0	2,010	21.7	2,550			21.7	2,560	21.7	2,560
30.0	1095	50.0	—	36.0	1,965	24.0	2,400			24.0	2,400	24.0	2,400
31.4	1010			40.0	1,960	26.0	2,300			26.0	2,300	26.0	2,300
31.5	740			40.0	—	28.0	1,940			28.0	1,940	28.0	1,940
42.0	730					30.0	1,600			30.0	1,600	30.0	1,600
47.0	685					30.0	—			30.0	—	36.0	3,000
55.0	640												
55.0	--												

Standard-Mobility Vehicles

M151A2		M715E1		M35A2		M54A2C		M815	
Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb
0.0	2195	0.0	7460	0	14,613	0	14,013	0	26,155
4.9	2185	2.8	7450	2.2	13,899	2.2	13,899	2.0	26,052
7.5	2050	3.6	7350	3.2	12,991	3.2	12,991	2.4	25,796
10.0	1815	4.3	6950	4.3	21,374	4.3	11,374	2.6	25,028
10.1	1205	5.0	6160	4.4	7,826	4.4	7,026	3.1	21,956
12.0	1180	5.1	3920	5.4	7,484	5.4	7,484	3.2	14,941
15.5	1085	6.3	3910	6.6	6,973	6.6	6,973	4.0	14,796
15.8	870	8.1	3830	8.0	6,325	8.0	6,325	4.9	13,065
19.9	660	9.3	3380	8.1	6,098	8.1	6,098	5.5	13,057
23.0	650	10.3	3290	8.6	5,769	8.6	5,769	5.6	12,033
26.0	615	10.6	3190	8.7	4,633	8.7	4,633	6.3	11,131
33.0	560	11.0	3040	10.6	4,486	10.6	4,486	6.4	8,049
33.1	420	11.1	2140	12.2	4,168	12.2	4,168	7.6	8,018
40.0	[illegible]	12.4	2100	13.8	3,736	13.8	3,736	9.0	7,681
45.0	355	15.0	2060	13.9	3,546	13.9	3,546	11.0	6,892
50.0	340	17.5	1970	15.9	3,248	15.9	3,248	11.1	6,790
55.0	310	20.1	1730	16.0	2,850	16.0	2,850	11.6	6,493
63.0	275	20.2	1630	18.4	2,714	18.4	2,714	11.7	6,803
63.0	--	21.1	1540	21.1	2,520	21.1	2,520	13.7	4,782
		21.1	1290	23.1	2,351	23.1	2,351	16.0	4,670
		25.0	1260	23.2	2,181	23.2	2,181	19.7	4,150
		25.0	1130	25.0	2,124	25.0	2,124	19.8	4,055
		33.9	1020	28.2	1,840	28.2	1,840	22.5	3,687
		34.0	890	28.3	1,783	28.3	1,783	22.6	3,584
		39.4	840	29.1	1,725	29.1	1,726	25.4	3,298
		39.5	530	29.2	1,385	29.2	1,385	25.5	2,478
		50.0	520	36.0	1,374	36.0	1,374	28.6	2,468
		60.0	500	42.0	1,272	42.0	1,272	35.4	2,263
		60.0	—	45.0	1,102	45.0	1,102	40.3	2,058
				45.1	1,090	45.1	1,090	40.4	1,905
				41.0	1,036	51.0	1,036	45.4	1,772
				53.0	1,012	53.0	1,011	50.0	1,649
				58.0	919	58.0	919	50.0	—
				58.0	--	58.0	—		

M52		M813		M125E1		M816/M817/XLC		M60A2	
Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb	Vehicle Speed mph	Tractive Force lb
0	23,164	0	25,540	0	32,545	0	25,732	0	77,240
2.0	23,066	2.0	25,440	1.9	32,345	2.0	25,632	2.0	55,130
2.4	22,838	2.6	25,190	2.2	31,945	2.4	25,380	4.0	39,130
2.6	22,132	2.6	24,440	2.6	30,545	2.6	24,624	6.0	27,760
3.1	19,445	3.1	21,440	2.8	28,045	3.1	21,602	8.0	20,820
3.2	13,246	3.2	14,590	3.2	25,545	3.2	14,700	10.0	16,180
4.0	13,181	4.0	14,540	3.3	24,245	4.0	14,650	12.0	10,920
4.9	12,267	4.9	13,540	3.6	19,045	4.9	13,642	14.0	9,876
5.5	11,542	5.5	12,750	3.6	18,945	5.5	12,846	16.0	7,970
5.6	10,655	5.6	11,750	4.0	18,545	5.6	11,838	18.0	6,710
6.3	9,853	6.3	10,860	4.3	18,045	6.3	10,942	20.0	5,650
6.4	7,112	6.4	7,860	5.0	16,445	6.4	7,919	22.0	4,610
7.6	7,099	7.6	7,830	5.6	14,755	7.6	7,889	24.0	3,970
9.0	6,802	9.0	7,500	5.7	11,860	9.0	7,557	26.0	3,350
11.0	6,104	11.0	6,730	6.0	11,855	11.0	6,781	28.0	3,130
11.1	6,003	11.1	6,630	6.6	11,375	11.1	6,680	30.0	2,500
11.6	5,742	11.6	6,340	7.4	11,085	11.6	6,388	30.0	—
11.7	4,236	11.7	4,690	8.1	10,595	11.7	4,725		
13.7	4,235	13.7	4,670	8.6	9,605	13.7	4,705		
16.0	4,137	16.0	4,540	9.5	9,335	16.0	4,596		
19.7	3,687	19.7	4,060	10.0	8,625	19.7	4,091		
19.8	3,549	19.8	3,960	10.1	7,625	19.8	3,990		
22.5	3,263	22.5	3,600	10.6	7,335	22.5	3,627		
22.6	3,174	22.6	3,500	11.6	7,355	22.6	3,526		
25.4	2,920	25.4	3,220	13.0	6,985	25.4	3,244		
25.5	2,186	25.5	2,420	14.2	6,510	25.3	2,438		
29.6	2,100	28.6	2,410	15.0	6,230	28.6	2,428		
35.6	1,990	35.4	2,210	16.6	5,360	35.4	2,227		
40.3	1,826	40.3	2,010	16.7	4,360	40.3	2,025		
40.6	1,687	40.4	1,860	18.0	4,290	40.4	1,874		
45.6	1,566	45.6	1,730	20.0	4,030	45.4	1,743		
50.0	1,468	50.0	1,610	22.7	3,585	50.0	1,622		
50.0	—	50.0	—	25.6	3,095	50.0	—		
				27.7	2,905				
				27.6	2,425				
				30.0	2,420				
				34.0	2,415				
				38.0	2,410				
				41.2	2,380				
				41.2	—				

Table F4

Obstacle Height-Speed Relations for Vehicle Characteristic No. 51 in Table 1

High Mobility Vehicles

M561		M656		M548E1		M520E1		TDW901		M553		M559	
Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph
0	100.0	0	50.0	0	100.0	0	100.0	0	55.0	0	100.0	0	100.0
4.5	100.0	0.1	50.0	5.5	100.0	5.5	100.0	0.1	55.0	5.5	100.0	5.5	100.0
4.5	40.0	4.35	50.0	5.8	60.0	5.5	60.0	5.99	55.0	5.5	60.0	5.5	60.0
5.0	30.0	4.62	40.0	6.0	40.0	6.0	34.0	6.00	48.0	6.0	34.0	6.0	34.0
6.0	18.0	5.00	33.0	6.5	20.0	6.5	20.0	6.40	40.0	6.5	20.0	6.5	20.0
8.0	10.0	5.6	26.0	7.5	11.0	7.0	16.0	7.00	33.0	7.0	16.0	7.0	16.0
10.0	8.0	6.0	22.3	8.0	9.0	8.0	8.0	7.4	30.0	8.0	8.0	8.0	8.0
15.0	5.0	7.0	17.2	9.0	8.5	10.0	4.0	8.00	26.0	10.0	4.0	10.0	4.0
20.0	4.0	8.0	14.0	10.0	7.0	15.0	2.0	9.00	22.0	15.0	2.0	15.0	2.0
30.0	3.0	10.0	9.7	20.0	5.0	25.0	2.0	10.0	18.2	25.0	2.0	25.0	2.0
50.0	3.0	12.0	7.2	30.0	4.0	50.0	1.0	12.0	13.0	50.0	1.0	50.0	1.0
		14.0	5.7	50.0	3.0			14.0	9.8				
		16.0	4.7					16.0	8.7				
		18.0	3.8					18.0	8.0				
		50.0	0.6					50.0	0.6				

Standard-Mobility Vehicles

M151A2		M715E1		M35A2		M49A2C		M816		M821		M813		M125E1		M818/M127A1C		M6[illegible]A2	
Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph	Obs Mag in.	Vehicle Speed mph
0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	60.0
4.5	60.0	5.5	100.0	3.7	100.0	3.7	100.0	4.5	100.0	4.8	100.0	4.5	100.0	4.8	100.0	1.0	100.0	9.0	60.0
4.9	30.0	5.5	60.0	4.2	80.0	4.2	80.0	5.0	80.0	5.0	86.0	5.0	80.0	5.0	86.0	1.0	80.0	9.3	30.0
5.2	20.0	5.6	50.0	4.8	56.0	4.8	56.0	5.5	60.0	5.2	70.0	5.5	60.0	5.2	70.0	1.5	56.0	9.8	16.0
6.0	9.0	5.8	40.0	5.0	52.0	5.0	52.0	6.0	40.0	5.4	60.0	6.0	40.0	5.4	60.0	2.0	44.0	10.0	12.5
7.2	5.0	6.2	30.0	5.8	40.0	5.8	40.0	7.0	22.0	5.7	50.0	7.0	22.0	5.7	50.0	3.0	30.0	11.0	7.0
10.4	3.0	6.7	20.0	6.7	30.0	6.7	30.0	8.0	16.0	6.0	40.0	8.0	16.0	6.0	40.0	4.0	21.0	12.0	5.9
16.4	2.0	7.0	14.0	8.4	20.0	8.4	20.0	9.0	10.0	6.5	30.0	9.0	10.0	6.5	30.0	5.0	16.0	13.5	5.0
50.0	2.0	8.5	8.0	10.0	13.0	10.0	13.0	10.0	7.0	7.5	20.0	10.0	7.0	7.5	20.0	7.5	10.0	15.0	2.5
		10.0	6.0	11.5	10.0	11.5	10.0	12.5	4.0	8.0	15.0	12.5	4.0	8.3	15.0	9.0	8.0	50.0	2.5
		12.0	4.0	15.0	6.0	15.0	6.0	15.0	2.8	9.0	10.0	15.0	2.8	9.0	10.0	12.0	6.0		
		14.0	3.0	20.0	3.2	20.0	3.2	20.0	2.0	10.0	7.0	20.0	2.0	10.0	7.0	18.0	4.0		
		17.5	2.0	25.0	2.0	25.0	2.0	25.0	1.0	11.0	6.0	25.0	1.0	11.0	6.0	30.0	3.0		
		50.0	2.0	50.0	0.6	50.0	6.0	50.0	1.0	13.0	5.0	50.0	1.0	13.0	5.0	50.0	1.0		
										15.0	4.0			15.0	4.0				
										20.0	3.0			20.0	3.0				
										25.0	2.0			25.0	2.0				
										30.0	1.5			30.0	1.5				
										35.0	1.0			35.0	1.0				
										50.0	0.6			50.0	0.6				

Table F5

Cross-Country Ride-Speed Relations for Vehicle Characteristic No. 53 in Table 1

High Mobility Vehicles													
M561		M656		M548E1		M520E1		1DW901		M553		M559	
RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph
0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0
0.15	60.0	0.24	80.0	0.34	80.0	0.10	100.0	0.24	80.0	0.10	100.0	0.10	100.0
0.17	40.0	0.25	50.0	0.35	60.0	0.20	40.0	0.23	54.0	0.20	40.0	0.20	40.0
0.25	30.0	0.34	30.0	0.36	40.0	0.30	24.0	0.30	40.0	0.30	24.0	0.30	24.0
0.50	20.0	0.50	22.5	0.40	30.0	0.35	20.0	0.50	29.2	0.35	20.0	0.35	20.0
1.00	15.5	0.75	19.6	0.45	25.0	0.50	14.0	0.75	24.1	0.50	14.0	0.50	14.0
1.50	13.0	1.00	17.3	0.62	20.0	0.80	10.0	1.00	20.7	0.80	10.0	0.80	10.0
2.00	11.5	2.00	10.0	1.00	15.0	1.20	8.0	1.50	15.5	1.20	8.0	1.20	8.0
3.00	7.5	3.00	10.0	1.46	12.00	2.00	6.0	2.00	12.00	2.00	6.0	2.00	6.0
8.00	6.5	8.00	10.0	2.00	10.0	8.00	5.5	3.00	12.00	8.00	5.5	8.00	5.5
				3.00	9.0			8.00	12.00				
				8.0	6.0								

Standard-Mobility Vehicles																			
M151A2		M715F1		M35A2		M49A2C		M816		MM21		M813		M125E1		M818/M27A1C		M60A2	
RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph
0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	63.0
0.20	100.0	0.20	60.0	0.23	80.0	0.23	80.0	0.18	100.0	0.20	100.0	0.18	100.0	0.18	100.0	0.05	100.0	0.50	55.0
0.20	80.0	0.23	40.0	0.24	60.0	0.24	60.0	0.20	60.0	0.23	60.0	0.20	60.0	0.20	60.0	0.05	80.0	1.00	44.0
0.25	60.0	0.25	30.0	0.25	40.0	0.25	40.0	0.30	38.0	0.45	40.0	0.30	38.0	0.30	38.0	0.10	40.0	1.50	30.0
0.45	40.0	0.38	20.0	0.35	30.0	0.35	30.0	0.40	31.0	0.80	26.0	0.40	31.0	0.40	31.0	0.20	26.0	2.00	20.0
0.60	32.0	0.50	16.5	0.46	25.0	0.46	25.0	0.60	24.0	1.20	18.0	0.60	24.0	0.60	24.0	0.30	18.0	2.50	16.0
0.80	25.0	1.00	13.0	0.72	20.0	0.72	20.0	0.80	20.0	1.70	12.0	0.80	20.0	0.80	20.0	0.50	13.0	2.75	14.0
1.00	21.0	1.50	11.0	1.00	16.6	1.00	16.6	1.05	16.0	2.20	8.0	1.05	16.0	1.05	16.0	0.70	12.0	3.00	13.0
1.30	16.0	2.00	8.5	1.17	15.0	1.17	15.0	1.20	14.0	3.00	6.0	1.20	14.0	1.20	14.0	1.00	11.0	4.00	11.5
1.60	11.0	3.00	7.0	2.00	10.0	2.00	10.0	1.70	10.0	8.00	5.7	1.70	10.0	1.70	10.0	1.50	8.5	5.00	10.5
2.00	9.0			3.00	8.0	3.0	8.0	2.20	8.0			2.20	8.0	2.20	8.0	2.00	8.0	6.00	10.0
2.50	7.0			8.00	6.0	8.0	6.0	3.0	7.0			3.0	7.0	3.0	7.0	3.00	6.5	8.00	9.0
3.00	5.0							8.0	6.0			8.0	6.0	8.0	6.0	6.00	3.0		
4.00	2.5															8.00	1.0		
5.00	2.0																		
8.00	2.0																		

Table F6

Roads and Trails Ride-Speed Relations for Vehicle Characteristics No. 55 in Table 1

High Mobility Vehicles													
M561		M656		M548E1		M520E1		TDW901		M553		M559	
RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph
0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0
0.20	60.0	0.24	80.0	0.41	80.0	0.10	100.0	0.45	80.0	0.10	100.0	0.10	100.0
0.50	35.0	0.25	50.0	0.42	60.0	0.20	40.0	0.50	50.0	0.20	40.0	0.20	40.0
0.66	30.0	0.50	37.5	0.43	40.0	0.30	32.0	0.75	32.5	0.30	32.0	0.30	32.0
1.00	23.5	0.75	30.5	0.50	33.1	0.40	28.0	1.00	27.9	0.40	28.0	0.40	28.0
1.50	15.5	1.00	26.2	0.79	25.0	0.65	20.0	1.50	20.7	0.65	20.0	0.65	20.0
2.00	10.6	2.00	11.3	1.00	21.8	1.00	15.0	2.00	16.3	1.00	15.0	1.00	15.0
3.00	3.0	2.30	9.2	1.60	15.0	1.60	10.0	2.30	15.3	1.60	10.0	1.60	10.0
8.00	2.9	3.00	9.2	2.00	11.2	2.30	6.0	3.00	15.3	2.30	6.0	2.30	6.0
		8.00	9.2	3.00	9.0	8.00	5.5	8.00	15.3	8.00	5.5	8.00	5.5
				8.00	7.5								

Standard-Mobility Vehicles																			
M151A2		M715E1		M35A2		M49A2C		M816		M821		M813		M125E1		M810/M127A1C		M60A2	
RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph	RMS in.	Vehicle Speed mph
0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	65.0
0.20	100.0	0.20	100.0	0.49	80.0	0.49	80.0	0.18	100.0	0.20	100.0	0.18	100.0	0.18	100.0	0.05	100.0	0.50	65.0
0.20	80.0	0.25	60.0	0.50	60.0	0.50	60.0	0.30	68.0	0.25	80.0	0.30	68.0	0.30	68.0	0.05	80.0	1.00	44.0
0.25	60.0	0.26	40.0	0.54	50.0	0.54	50.0	0.55	55.0	0.43	60.0	0.55	55.0	0.55	55.0	0.10	70.0	1.50	30.0
0.45	41.0	0.33	30.0	0.61	40.0	0.61	40.0	0.80	40.0	0.70	45.0	0.80	40.0	0.80	40.0	0.20	58.0	2.00	20.0
0.60	36.0	0.50	23.5	0.77	30.0	0.77	30.0	1.47	22.0	1.20	30.0	1.47	22.0	1.47	22.0	0.30	49.0	2.50	16.0
0.80	30.0	0.68	20.0	0.93	25.0	0.93	25.0	2.20	10.0	1.70	20.0	2.20	10.0	2.20	10.0	0.50	38.0	2.75	14.0
1.00	26.0	1.00	16.0	1.00	23.5	1.00	23.5	2.80	6.8	2.30	10.0	2.80	6.8	2.80	6.8	0.70	30.0	3.00	13.0
1.30	21.0	1.75	10.0	1.50	15.0	1.50	15.0	8.00	6.0	3.00	6.0	8.00	6.0	8.00	6.0	1.00	23.0	4.00	11.5
1.60	17.0	2.00	8.5	2.00	10.5	2.00	10.5			5.70	8.0					1.50	14.0	5.00	10.5
2.00	11.0	3.00	6.0	3.00	4.8	3.00	4.8									2.00	10.0	6.00	10.0
2.50	8.0	8.00	5.0	8.00	2.0	8.00	2.0									3.00	8.0	8.00	9.0
3.00	5.0															8.00	8.0		
4.00	2.5																		
5.00	2.0																		
4.00	2.0																		

components of lower amplitude and low-frequency components of higher amplitude than are usual for cross-country traverses with the same rms elevation. Six-watt vehicle ride-speed limits on roads and trails and on cross-country traverses, both characterized by the same rms elevation, are therefore somewhat different. The vehicle data accordingly includes two 6-watt ride-speed versus rms relations, one for use in predicting off-road performance and the other for predicting road and trail performance. Plots of the two ride-speed rms-elevation relations for the 17 study vehicles are given in Figures F1-F6.

5. Maximum likely speed of a vehicle crossing a single, minor discrete obstacle of the kind characterized as a recurring feature throughout an areal terrain unit is specified as that speed at which peak acceleration (passing a 30-Hz filter) at the driver's seat just reaches 2.5 g. AMM uses a speed versus obstacle-height relation for each vehicle to determine this speed limitation in making each terrain unit prediction. As in the case of ride-speed limits, the data supplied the model can be obtained by means of controlled vehicle tests or computer simulations of vehicle dynamics performance. The obstacle height-speed relations for the 17 study vehicles, obtained largely experimentally, are plotted in Figures F8-F9. Basic data sources are again identified in the complete data tables (F1-F6).

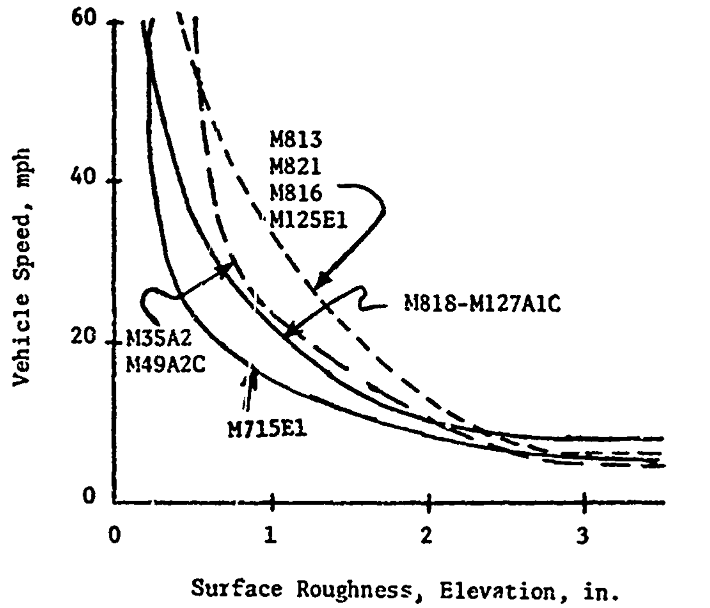

Figure F1. Trails and roads ride-speed relations for standard-mobility vehicles

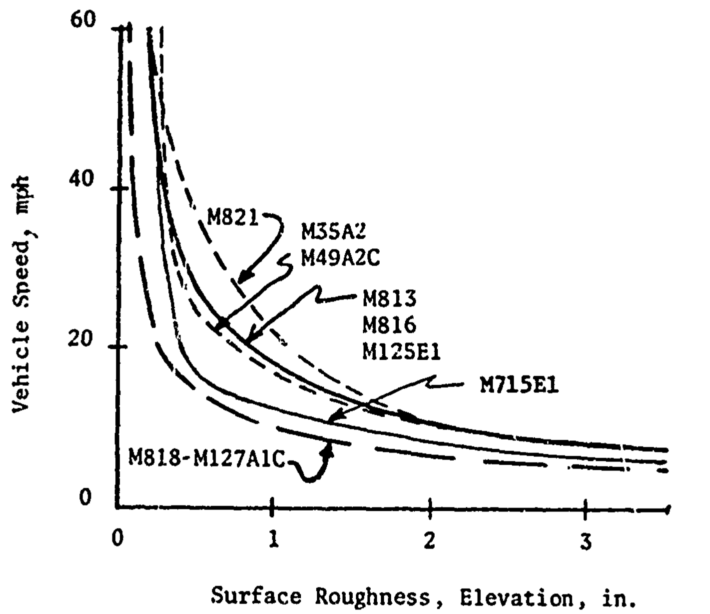

Figure F2. Off-road ride-speed relations for standard-mobility vehicles

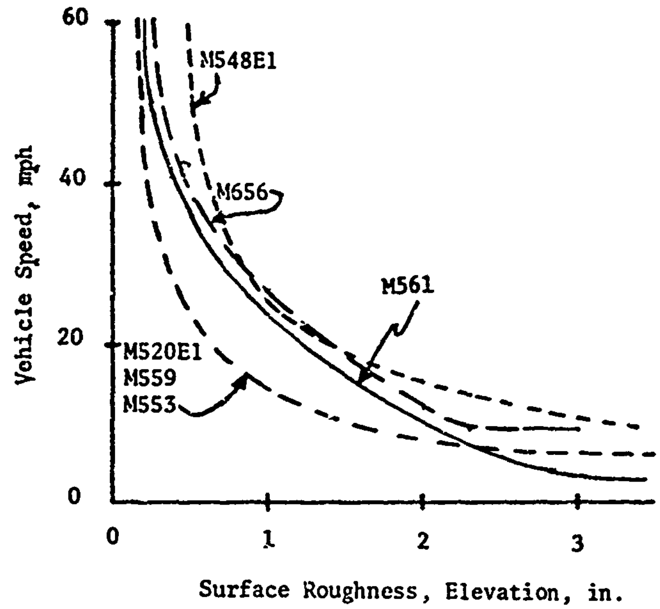

Figure F3. Trails and roads ride-speed relations for high-mobility vehicles

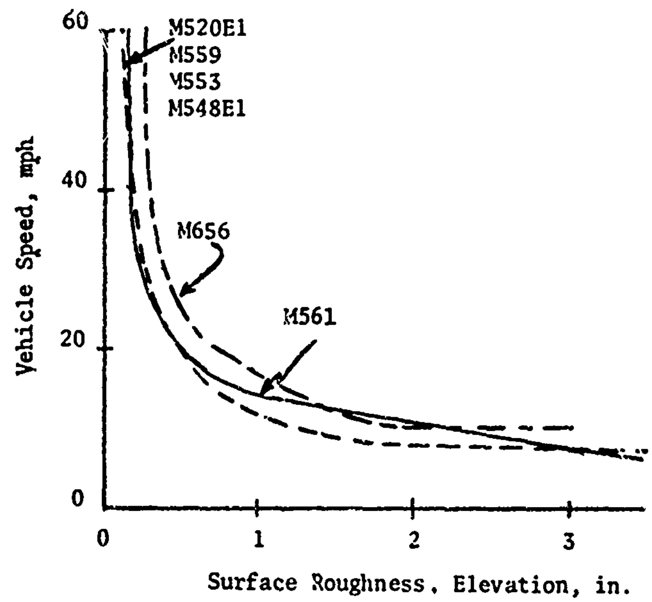

Figure F4. Off-road ride-speed relations for high-mobility vehicles

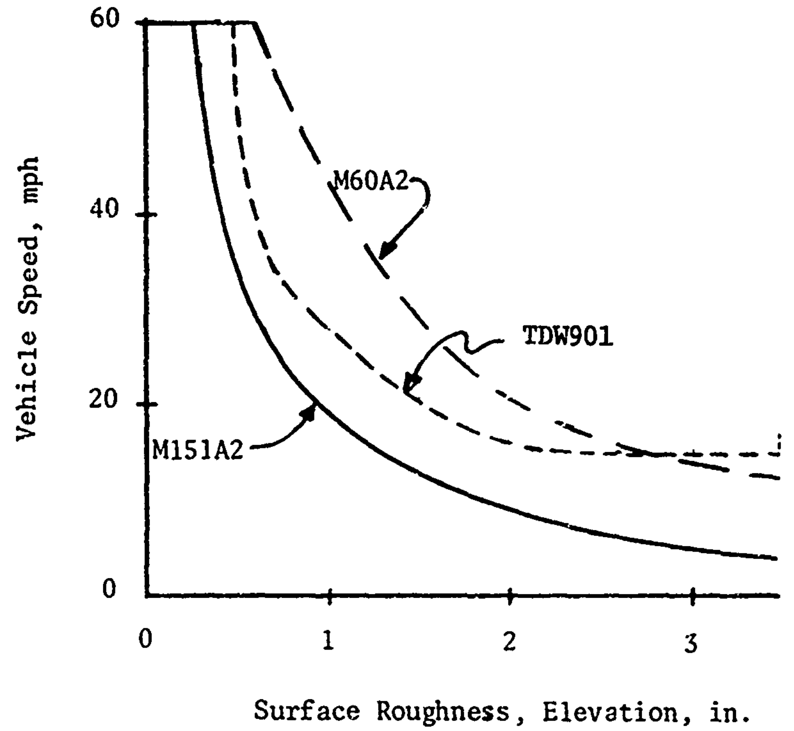

Figure F5. Trails and roads ride-speed relations for M60A2, TDW901, and M151A2

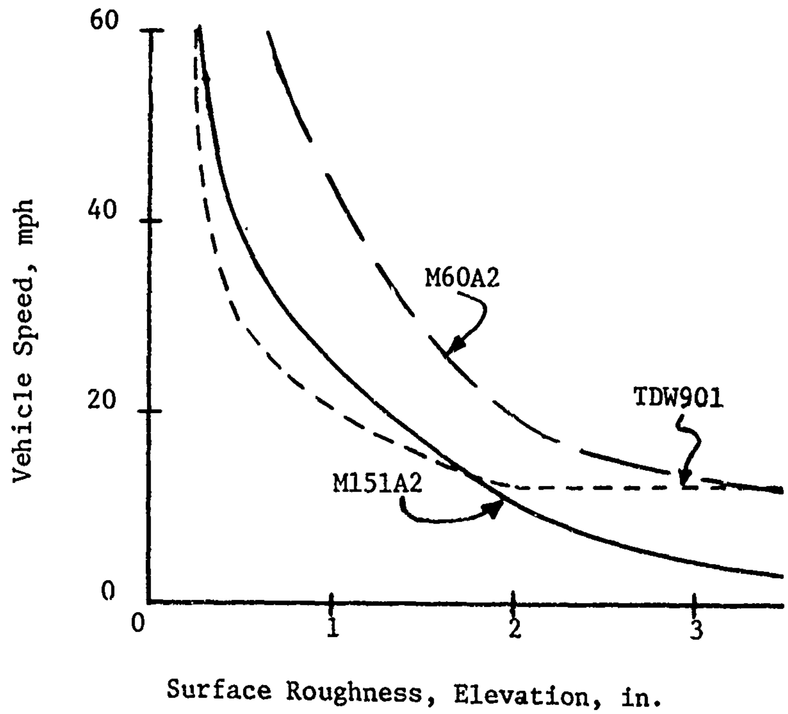

Figure F6. Off-road ride-speed relations for M60A2, TDW901, and M151A2

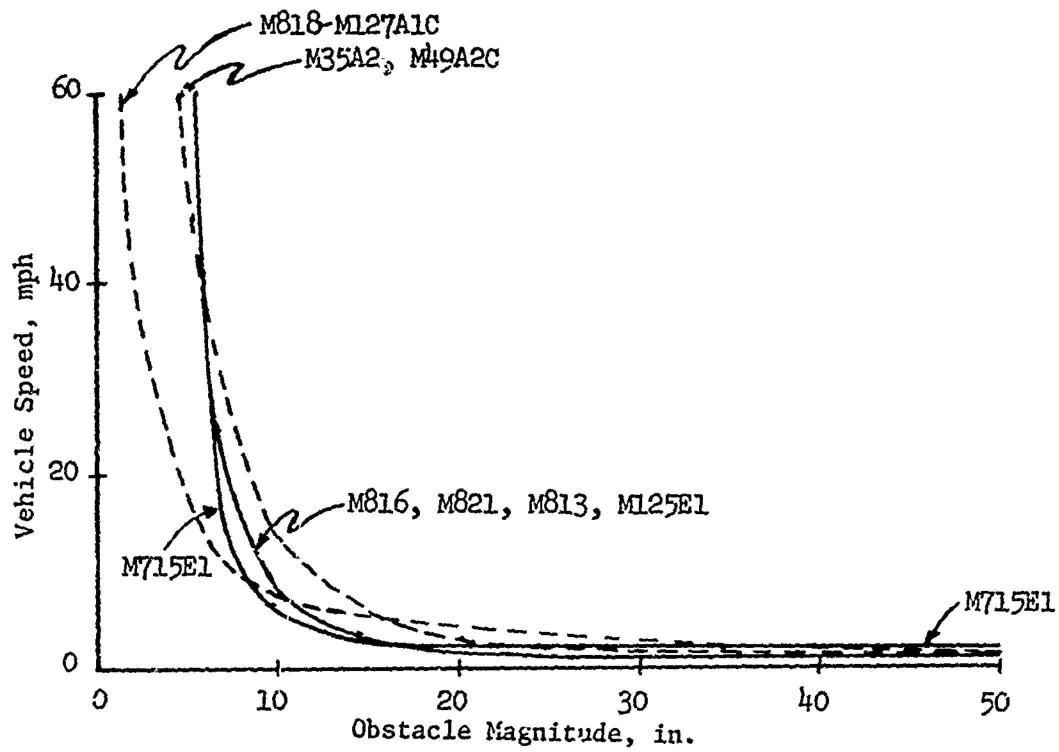

Figure F7. Obstacle height-speed relations for standard-mobility vehicles

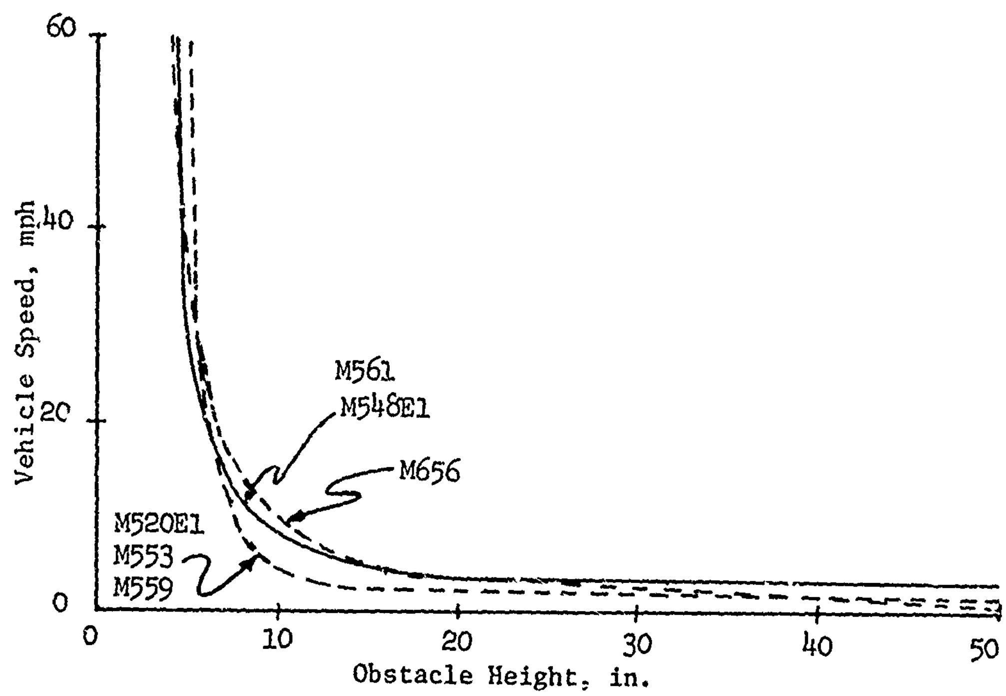

Figure F8. Obstacle height-speed relations for high-mobility vehicles

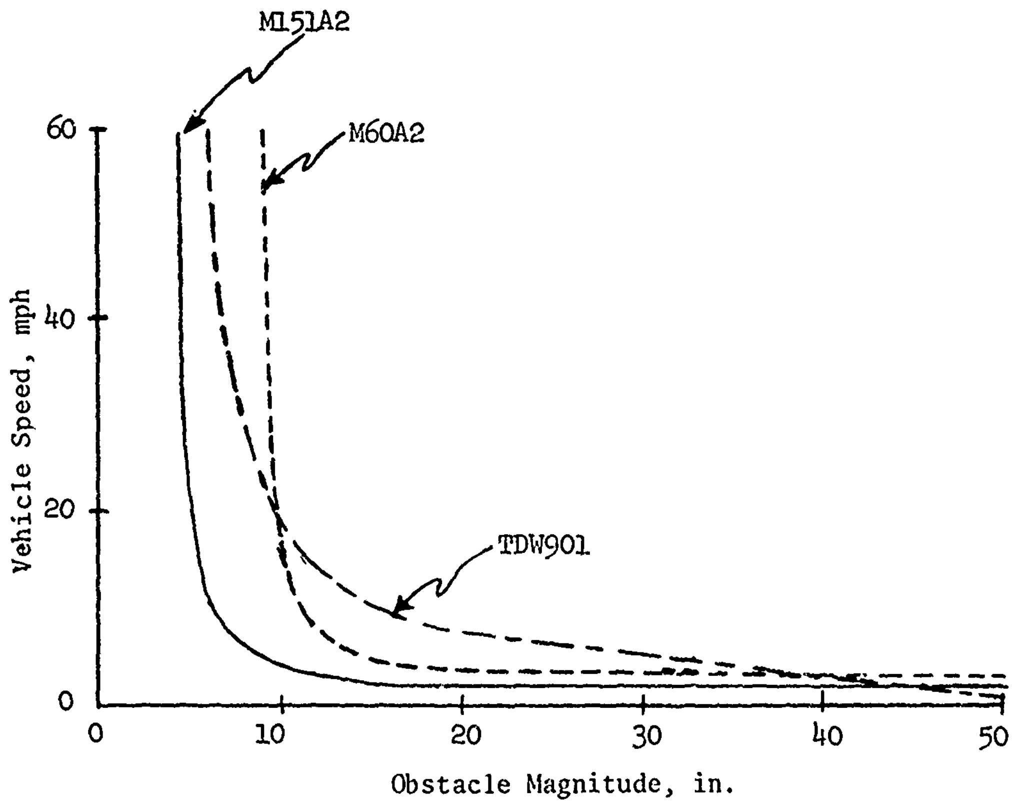

Figure F9. Obstacle height-speed relations for M60A2, M151A2, and TDW901

APPENDIX G: PARTICIPANTS IN SCENARIO EXERCISES

Mid-East Scenario, Fort Eustis, Va., 24-26 June 1974

NAME	RANK	ORGANIZATION
McClure, J.	Civ	USA Logistics Center Fort Lee, Va.
Gehler, W. C.	LTC	Force Development Task Force Fort Lee, Va.
Randolph, D. D.	Civ	USA Engineer Waterways Experiment Station, Vicksburg, Miss.
Rula, A. A.	Civ	USA Engineer Waterways Experiment Station, Vicksburg, Miss.
Nuttall, C. J.	Civ	USA Engineer Waterways Experiment Station, Vicksburg, Miss.
Martin, L.	Civ	USA Tank-Automotive Command Warren, Mich.
Hale, W. C.	Civ	USA Quartermaster School Fort Lee, Va.
Johnson, C. T.	CPT	USA Armor School Fort Knox, Ky.
Traas, A. G.	MAJ	USA Engineer School Fort Belvoir, Va.
McCormick, T.	CPT	USA Air Defense School Fort Bliss, Tex.
Adkins, D. C.	Civ	USA Field Artillery School Fort Sill, Okla.
Sikorski, R. J.	MAJ	USA Missile and Munitions Center School, Red Stone Arsenal, Ala.
McCarff, J. M.	LTC	USA Infantry School Fort Benning, Ga.
McDonald, J. A.	CPT	USA Ordinance Center and School Aberdeen Proving Ground, Md.
Turley, J. M.	MAJ	USA Combined Arms Combat Development Activity, Fort Leavenworth, Kan.
Binrup, L. W.	LTC	USA Combined Arms Combat Development Activity, Fort Leavenworth, Kan.
Morris, J. F.	MAJ	USA Transportation School Fort Eustis, Va.
Brown, E.	Civ	USA Transportation School Fort Eustis, Va.

West Germany Scenario, Waterways Experiment Station, 21-23 August 1974

NAME	RANK	ORGANIZATION
McClure, J.	Civ	USA Logistics Center Fort Lee, Va.
Gehler, W. C.	LTC	Force Development, Task Force Fort Lee, Va.
Morris, J. F.	MAJ	USA Transportation School Fort Eustis, Va.
Brown, E.	Civ	USA Transportation School Fort Eustis, Va.
Vincent, C. J.	MAJ	USA Engineer School Fort Belvoir, Va.
McCormick, T.	CPT	USA Air Defense School Fort Belvoir, Va.
Martin, L. A.	Civ	USA Tank-Automotive Command Warren, Mich.
Bane, Alfred	Civ	USA Combined Arms Combat Development Activity, Fort Leavenworth, Kan.
McDaniel, M.	MAJ	USA Fiedl Artillery Fort Sill, Okla.
Fabian, J. A. R.	CPT	USA Infantry School Fort Benning, Ga.
Johnson, C. T.	CPT	USA Armor School Fort Knox, Ky.
McEachin, R. R.	Civ	USA Materiel Systems Analysis Activity, Aberdeen Proving Ground, Md.
Hurford, E. C.	Civ	USA Combat Development Command Fort Lee, Va.
Berry, Gordon	MAJ	Modern Army Selective Systems Test Evaluation and Review, Fort Hood, Tex.
East	MAJ	Modern Army Selective Systems Test Evaluation and Review, Fort Hood, Tex.
Jones, Kirk	Civ	Modern Army Selective Systems Test Evaluation and Review, Fort Hood, Tex.
Rula, A. A.	Civ	USA Engineer Waterways Experiment Station, Vicksburg, Miss.
Nuttall, C. J.	Civ	USA Engineer Waterways Experiment Station, Vicksburg, Miss.
Robinson, J.	Civ	USA Engineer Waterways Experiment Station, Vicksburg, Miss.
Temple, B.	Civ	USA Engineer Waterways Experiment Station, Vicksburg, Miss.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Nuttall, Clifford J
Mobility analyses of standard- and high-mobility tactical support vehicles (HIMO study), by C. J. Nuttall, Jr., [and] D. D. Randolph. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.
1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Technical report M-76-3)
Prepared for U. S. Army Training and Doctrine Command, Fort Monroe, Virginia.
Includes bibliography.

1. Off-road mobility. 2. On-road mobility. 3. Vehicle performance. 4. Ground mobility model. 5. Mobility maps. 6. Terrain maps. 7. Mission performance. I. Randolph, Donald D., joint author. II. U. S. Army Training and Doctrine Command. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Technical report M-76-3)
TA7.W34 no.M-76-3

G3